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Second Topical Conference

on

High-Temperature Plasma Diagnostics

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Second Topical Conference on High-Temperature Plasma Diagnostics

Compiled by

Franz C. Jahoda
Kenneth B. Freese

Santa Fe Hilton Inn
Santa Fe, New Mexico 87501
March 1–3, 1978

UNITED STATES
DEPARTMENT OF ENERGY
CONTRACT W-7405-ENG. 36

SECOND APS TOPICAL CONFERENCE ON

HIGH-TEMPERATURE PLASMA DIAGNOSTICS

PROGRAM AND ABSTRACTS

Compiled by

F. C. Jahoda
and
K. B. Freese

ABSTRACT

This report contains the program and abstracts of papers presented at the Second American Physical Society Topical Conference on High Temperature Plasma Diagnostics, March 1-3, 1978, Santa Fe, New Mexico.

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PROGRAM

THE SECOND APS TOPICAL CONFERENCE
ON
HIGH TEMPERATURE PLASMA DIAGNOSTICS

Tuesday, February 28, 1978

2:00 to 9:00 p.m.	Registration, Lobby - Promenade

Wednesday, March 1

8:00 a.m.	Registration, Lobby - Promenade
8:30 a.m.	Poster Set Up
9:00 a.m.	Session A, International Room
10.30 a.m.	Coffee, Promenade - Poster Session, International Room
12:30 p.m.	Lunch
1:30 p.m.	Poster Set Up
2:00 p.m.	Session B, International Room
3:45 p.m.	Refreshments, Promenade - Poster Session, International Room
6:30 p.m.	Reception, International Room

Thursday, March 2

8:00 a.m.	Poster Set Up
8:30 a.m.	Session C, International Room
10:15 a.m.	Coffee, Promenade - Poster Session, International Room
12:15 p.m.	Lunch
2:30 p.m.	Buses leave, Front of Santa Fe Hilton Inn
3:30 p.m.	Tours of Los Alamos Scientific Laboratory
5:30 p.m.	Reception (Cash Bar), Los Alamos Community Building
6:45 p.m.	Banquet
8:45 p.m.	Return to Santa Fe

Friday, March 3

8:30 a.m.	Poster Set Up
9:00 a.m.	Session D, International Room
10:15 a.m.	Coffee, Promenade - Poster Session, International Room
12:15 p.m.	Lunch
1:30 p.m.	Poster Set Up
2:00 p.m.	Session E, International Room
3:15 p.m.	Refreshments, Promenade - Poster Session, International Room

SCHEDULE

Session A

FAR INFRARED DIAGNOSTICS AND SYNCHROTRON RADIATION

9:00 a.m., Wednesday, March 1, 1978
International Room

Chairman: N. C. Luhmann, Jr., University of California Los Angeles

9:00		Opening Remarks, H. Dreicer, CTR Division Leader, Los Alamos Scientific Laboratory
9:15	A1	Far Infrared Diagnostics, Daniel R. Cohn (Invited Speaker)
9:45	A2	Plasma Diagnostics Using Electron Cyclotron Emission, D. A. Boyd (Invited Speaker)
10:15		Poster Session Overview
10:30		Coffee

Poster Session

A3	High Power Laser and Low Noise Receiver For Submillimeter Thomson Scattering Ion Temperature Diagnostic, P. Woskoboinikow, H. C. Praddaude, D. R. Cohn
A4	A Submillimeter-Laser Polarimeter for the Measurement of Faraday Rotation in a Plasma, D. P. Hutchinson, K. L. Vander Sluis, C. H. Ma, and P. A. Staats
A5	Development of Beam Dumps for Submillimeter-Laser Scattering Experiments, P. A. Staats, D. P. Hutchinson, K. L. Vander Sluis, and D. M. Thomas
A6	A One-Megawatt D_2O Oscillator-Amplifier System, K. L. Vander Sluis, P. A. Staats, and D. P. Hutchinson
A7	FIR Lasers for Plasma Diagnostics, A. Semet, N. C. Luhmann, Jr., and W. A. Peebles, D. T. Hodges, F. Foote, and R. D. Reel

A8 CW FIR Laser Scattering from Driven Ion Acoustic Waves, W. A. Peebles, A. Semet, N. C. Luhmann, Jr., Th. de Grauuw, and J. Gustincic

A9 A Multichannel Electron Temperature Diagnostic for Tokamaks Using Cyclotron Radiation, G. D. Tait and D. A. Boyd

A10 Swept-Heterodyne Cyclotron Emission Receiver Measurements of the Electron Temperature Profiles in PLT, V. Arunasalam, P. C. Efthimion, and J. Hosea

A11 Ordinary-Mode Fundamental Cyclotron Emission in PLT, P. C. Efthimion, V. Arunasalam, and J. Hosea

A12 Tokamak Synchrotron Radiation Measurements Using Conventional and Quasi-Optical Schottky Diode Heterodyne Receivers, N. C. Luhmann, Jr., W. A. Peebles, A. Semet, Th. de Grauuw, and J. Gustincic

A13 Radiometric Measurements of T_e on Doublet IIA, John Lohr and R. K. Fisher

A14 Temporal Variation of T_e in LITE, J. H. Stufflebeam

A15 Collision Effects on Light Scattering by Plasmas Containing Ionized Impurities, O. Theimer and A. N. Sandalov

A16 Development of Diagnostic Techniques for ALVAND-2 Tokamak, R. Aghevli, M. Amini-Rad, M. Avakian, H. Azodi, M. Naraghi, B. Rezvani, and M. H. Tabatabai

Session B

DIAGNOSTICS OF HIGH DENSITY PLASMAS

2:00 p.m., Wednesday, March 1, 1978
International Room

Chairman: D. J. Nagel, Naval Research Laboratory

2:00	B1	The Sandia Laboratories Diagnostic System for Particle Beam Fusion Experiments, R. J. Leeper (Invited Speaker)
2:30	B2	Recent X-Ray Analysis of Laser-Fusion Plasma, Ping Lee (Invited Speaker)
3:00	B3	Plasma Physics Experiments on a Scale of Microns and Picoseconds, David Attwood (Invited Speaker)
3:30		Poster Session Overview
3:45		Refreshments

Poster Session

B4	Physics and Application of Secondary Electron Emission from X-Ray Photocathodes, B. L. Henke
B5	Ultrasoft X-Ray Calibration of X-Ray-Diodes for Laser Fusion Plasma Diagnostics, R. H. Day, P. Lee, T. L. Elsberry, E. B. Saloman, and D. J. Nagel
B6	Fast, Large Signal, Free Standing Foil Bolometer for Measuring Ultrasoft X-Ray Burst Fluence, J. H. Degnan, M. C. Clark, R. E. Reinovsky, G. F. Kiuttu, and G. Kahn
B7	A Twin Pendulum Device for Plasma Diagnostics, B. Arad, S. Eliezer, Y. Gazit, H. M. Loebenstein, M. Rosenblum A. Zigler, H. Zmora, and S. Zweigenbaum
B8	Investigation of the Transient Regime of Laser Produced Plasma by Space Resolved X ray Spectroscopy, A. Zigler, H. Zmora, H. M. Loebenstein, and J. L. Schwob
B9	X-Ray Image Intensifier, R. E. McDonald

B10 Space Charge Effects in Laser Plasma Particle Diagnostics, Steven J. Gitomer and Henry Brysk

B11 An Electrostatic, Ion/Electron Spectrometer for Laser-Produced Plasma Measurements, D. Woodall and C. Shaffer

B12 Soft X-Ray Diagnostics of CO_2-Laser-Heated Magneto-Plasma, N. G. Loter, W. Halverson, and C. V. Karmendy

B13 X-Ray Spectra of Vacuum Spark Plasmas, T. N. Lee, J. F. Seely, and R. C. Elton

B14 Determination of the Size of the X-ray Line Emitting Point Source, R. U. Datla

B15 Line and Continuum Radiation as a Liner Implosion Diagnostic, L. J. Suter, D. M. Kraybill, I. R. Lindemuth, and J. C. Stevens

B16 Measurements of Field Reversal with a One-Turn Loop Encircling the Plasma, J. D. Sethian, K. A. Gerber, D. N. Spector, and A. E. Robson

Session C

Laser Scattering, Interferometry, and Data Handling

8:30 a.m., Thursday, March 2, 1978
International Room

Chairman, R. H. Lovberg, University of California San Diego

8:30	C1	CO_2 Laser Scattering, C. M. Surko (Invited Speaker)
9:00	C2	Heterodyne Interferometry, R. Kristal (Invited Speaker)
9:30	C3	Trends in Data Acquisition--Systems Which Wear Well, Daniel D. Drobnis (Invited Speaker)
10:00		Poster Session Overview
10:15		Coffee

Poster Session

C4 A Doubled Nd-Glass Laser System for Low Density Incoherent Thomson Scattering, B. A. Jacoby, T. M. York, and R. A. Mollo

C5 The Measurement of Magnetic Fields in Tokamaks by the Detection of the Cyclotron Modulated Scattered Laser Light Spectrum, M. J. Forrest, P. G. Carolan, and N. J. Peacock

C6 Scattering with Periodically Pulsed YAG-Lasers for Time-resolved T_e- and n_e Measurements, H. F. Dobele, K. Hirsch, E. Holzhauer, R. Reischl

C7 Forward Scattering at 10.6 μ Using Heterodyne Detection to Measure Ion Temperature, E. Holzhauer and J. H. Massig

C8 Thomson Scattering Diagnostics for PDX, C. C. Daughney

C9 Diagnostics Development For the PCX Laser Heated Solenoid Experiment, E. A. Crawford, D. D. Lowenthal, and A. L. Hoffman

C10 A Multichannel Ruby Laser Scattering Device for the TFR Tokamak, TFR Group, (P. Platz)

C11 90° CO_2 Thomson Scattering from a Pulsed Hydrogen Arc, M. J. Herbst and W. A. Peebles

C12 A Small-Angle CO_2 Scattering System Employing Beam Apodization and Homodyne Detection, T. Angel, P. Hudson, J. Shlachter, and R. Lovberg

C13 Infrared Heterodyne Interferometer for Multichord Plasma Density Measurements, A. R. Jacobson

C14 Measurements of the Plasma Ablated from an End Plug in a High Energy Theta Pinch Using Ruby Laser Side-Viewing Holographic Interferometry, C. A. Ekdahl, R. J. Commisso, K. F. McKenna, and R. E. Siemon

C15 Measurement of Line Density With a Multipass Interferometer, W. T. Armstrong and G. Miller

C16 Measurements of Plasma Temperature Using Stimulated Brillouin Scattering in a Laser Heated Solenoid, Z. A. Pietrzyk, T. Carlstrom, and D. W. Scudder

C17 Proposed Method of Measuring Directed Electron Velocities Using the Incoherent Regions of Laser Scattering, B. A. Jacoby and T. M. York

C18 Direct-Readout Microwave Interferometer, J. Fujita and K. Matsuura

C19 Computer Analysis of 2-D Holographic Interferograms, R. Conrad and K. B. Freese

C20 A Fluctuation-Induced Transport Diagnostic Based Upon FFT Spectral Analysis, E. J. Powers, J. Y. Hong, Y. C. Kim, J. R. Roth, and W. M. Krawczonek

C21 Testing Transient Recorder Linearity, K. A. Klare

C22 Diagnostic Signal Transmission and Control Using Fibre Optic Links, K. Fullard

C23 Diagnostic Techniques with Stand Alone Capability, A. H. Read

Session D

Visible, UV, and X-Ray Diagnostics

9:00 a.m., Friday, March 3, 1978
International Room

Chairman, D. L. Dimock, Princeton Plasma Physics Laboratory

9:00 D1 Optical Standards for Plasma Diagnostics, Robert P. Madden (Invited Speaker)

9:30 D2 X-Ray Detectors for High Temperature Plasma Diagnostics, R. D. Bleach (Invited Speaker)

10:00 Poster Session Overview

10:15 Coffee

Poster Session

D3 A High-Time Resolving TV Camera System, N. Noda and J. Fujita

D4 Plasma Photography in Doublet III, J. F. Baur, D. R. Baker, and E. S. Ensberg

D5 Diagnostics of Impurities on Tokamak Surface by Laser Induced Desorption, F. Schwirzke, L. Oren, S. Talmadge, and R. Taylor

D6 Autoionizing States as an Insight into Dielectronic Recombination, W. E. Cooke and T. F. Gallagher

D7 Detection of Low Density Atoms by Intracavity Dye Laser Absorption and Enhancement, G. O. Brink and H. S. Lakkarajü

D8 Rapid Scanning of Spatial Distribution of Spectral Line Intensities in PLT Tokamak, S. Suckewer, E. Hinnov and J. Schivell

D9 Topics in XUV Spectroscopy of High Temperature Plasmas, N. J. Peacock, C. C. Smith, H. P. Summers

D10 EUV Spectroscopic Instrumentation for Plasma Diagnostics, H. W. Moos, W. G. Fastie and R. K. Richards

D11 A Spatial Imaging Detector for an EUV Monochromator, R. K. Richards and H. W. Moos

D12 Interpretation of ORMAK Impurity Radiation Data Using Simulation Models, E. C. Crume, R. C. Isler, and T. Amano

D13 Temperature Diagnostics Using Li-Like Satellites, R. U. Datla, L. A. Jones, and D. B. Thomson

D14 The Ultra-Soft X-Ray Array on PLT, D. R. Eames, S. Von Goeler, N. R. Sauthoff, and W. Stodiek

D15 Analysis Techniques for X-ray Fluctuation Measurements on PLT, N. R. Sauthoff, S. Von Goeler, and W. Stodiek

D16 Determination of Spatial Distribution of Volume Soft X-Ray Emission from Plasmas, A. P. Navarro, V. K. Pare, and J. L. Dunlap

D17 High Resolution X-Ray Spectrometer for Line Profile Analysis, P. O. Taylor and H. W. Schnopper

D18 A High Resolution Crystal Spectrometer, M. Bitter, S. Von Goeler, M. Goldman, K. Hill, R. W. Horton, N. Sauthoff, and W. Stodiek

D19 Fe Charge-State Distributions in PLT from Bragg X-Ray Spectroscopy, K. W. Hill, S. Von Goeler, B. Frankel, R. Horton, R. D. Cowan, and J. Hovey

D20 An Absolute Radiation Measurement and Comparison with Total Energy Loss, R. B. Howell, A. Haberstich and H. J. Karr

D21 Detectors and Techniques for Energy Flux Measurements on ISX, C. E. Bush

Session E

PARTICLE DIAGNOSTICS

2:00 p.m., Friday, March 3, 1978
International Room

Chairman: P. M. Stone, U. S. Department of Energy, Division of Magnetic Fusion Energy

2:00 E1 Mirror Machine Diagnostics, Thomas C. Simonen (Invited Speaker)

2:30 E2 Measurement of the Current Distribution in Tokamak Plasmas Using Neutral Lithium Beam Spectroscopy, K. McCormick (Invited Speaker), and M. Kick

3:00 Poster Session Overview

3:15 Refreshments

Poster Session

E3 Heavy Ion Beam Probing of Plasma Potential in Baseball Minimum-B Geometry, G. Thokar, J. T. Woo, W. C. Jennings, and R. L. Hickok

E4 The EBT Heavy Ion Beam Probe, K. A. Connor, S. P. Kuo, F. M. Bieniosek, R. L. Hickok, W. C. Jennings, and P. L. Colestock

E5 A Beam Probe System for the Central Region of TMX, G. Hallock, K. Saadatmand, W. C. Jennings, and R. L. Hickok

E6 Heavy Ion Beam Probe Vector Potential Measurement, J. A. Kolawole, T. R. Price, and K. A. Connor

E7 An Ion Beam Trajectory Code, Timothy A. Cutler and Robert S. Hornady

E8 Plasma Diagnostics by Neutral Beam Probing, K. Kadota K. Tsuchida, Y. Kawasumi and J. Fujita

E9 A Technique for Measuring Poloidal Field Via a Perpendicular Neutral Beam of H_2^0, F. C. Jobes

E10 PLT Neutron Measurements, J. D. Strachan, A. Bhattacharjee, P. Colestock, W. Stodiek, and R. W. Stooksberry

E11 TFTR Neutron Diagnostics, H. W. Hendel and S. W. Seiler

E12 Alpha-Particle Diagnostics on TFTR, S. W. Seiler and H. W. Hendel

E13 Perpendicular Charge Exchange Diagnostic for ISX-B, J. T. Mihalczo, G. H. Neilson, J. F. Lyon and R. E. Worsham

E14 Mass-Energy Neutral Analyzer for ISX, G. H. Neilson

E15 End Loss Analyzers on 2XIIB, A. W. Molvik

E16 Detection of MeV Ions from D-D Reactions in 2XIIB, James H. Foote

E17 <u>A Multi-Channel Magnetic Analyzer for Pulsed Plasma Sources</u>, John E. Osher

E18 <u>Measurements of Gettering Efficiency for a Simulated Divertor Plasma Flux</u>, M. Yamada and D. K. Owens

E19 <u>Charged Fusion-Product Detection in a Tokamak</u>, L. M. Hively and G. H. Miley

E20 <u>Measurement of the Molecular Content of Low Energy Deuteron or Triton Beams</u>, F. E. Cecil and K. Killian

FAR INFRARED DIAGNOSTICS *

Daniel R. Cohn

Plasma Fusion Center* and National Magnet Laboratory+
Massachusetts Institute of Technology
Cambridge, Mass. 02139

The characteristic parameters of magnetically confined plasmas of interest for controlled fusion dictate increased use of far infrared techniques for plasma diagnostics The development of these diagnostics draws heavily upon recent advances in optically pumped far infrared lasers. A modulated interferometer using a 119 μm optically pumped CH_3OH laser has been developed[1] and is employed to make routine measurements of the evolution of plasma density in the high density ($\bar{n} > 5 \times 10^{14}$ cm^{-3}) Alcator A tokamak device. Modulation is obtained by mixing the radiation of two highly stable CW laser lines separated in frequency by approximately 1 MHz. A large number of far infrared optically pumped submillimeter laser lines can be used for interferometric measurements. A 393 μm CH_3OOH interferometer is being developed for ISX. The relatively large number of available optically pumped far infrared laser lines also facilitates future measurements of cyclotron absorption which will complement cyclotron emission studies. A CW submillimeter laser polarimeter is being developed for Faraday rotation measurements of current profiles.[2] Submillimeter laser Faraday rotation can also be used to measure magnetic field changes in mirror devices. High power pulsed (∿1 MW) D_2O and CH_3F lasers are being developed at a number of laboratories in order to perform Thomson scattering measurements in the regime where the laser wavelength is greater than the Debye length. These measurements can be used to study collective phenomena and to obtain spatially resolved determinations of ion temperatures and impurity concentration in tokamak and mirror plasmas.[3,4] In these measurements the frequency shift of the scattered radiation will be determined by the use of a heterodyne detector system. The required heterodyne receivers which use state of the art Schottky barrier diodes have been developed. Far infrared scattering from ion acoustic waves in an unmagnetized filament discharge has recently been observed with CW far infrared sources.[5] High power far infrared radiation may be used in direct measurements of electron thermal conductivity by local heating at a harmonic of the electron cyclotron frequency.[3]

* Supported by DOE.
+ Supported by NSF.

1. S.M. Wolfe, K.J. Button, J. Waldmann and D.R. Cohn, Appl. Optics 15, 2645 (1976)
2. C.H. Ma, D.P. Hutchinson, K.L. Vandersluis (submitted for publication)
3. D.L. Jassby, D.R. Cohn, B. Lax and W. Halverson, Nucl. Fusion 14 745 (1974).
4. D.E. Evans and M.L. Yeoman, Phys, Rev. Lett. 33, 76 (1974).
5. Th. DeGraauw, J.J. Gustincic, N.C. Luhmann Jr. and A Semet (to be published)

Plasma Diagnostics Using Electron Cyclotron Emission,*

D. A. BOYD, University of Maryland, College Park, Maryland 20742

Two technologies have been used to measure the electron cyclotron emission from PLT. One group[1,2] has used conventional microwave equipment and concentrated on the emission at the fundamental frequency. A second group[3,4] has used quasi-optical infrared techniques and concentrated its attention on the second and higher harmonic emission. Both of these approaches have yielded several electron temperature profiles, which are scanned in 20 milliseconds, for a single discharge. Alternatively each has produced a continuous record of the temporal history of the electron temperature at one (four) radial position(s). Localized temperature fluctuations have been studied. Recently the most comprehensive data yet obtained on electron heating by neutral beam injection, was collected by these diagnostic systems.

*Supported in part by NSF and DOE.

[1] J. Hosea, V. Arunasalam, and R. Cano, Phys. Rev. Lett. 39, 408 (1977).
[2] P. Efthimion et al., Bull. Am. Phys. Soc. 22, 1140 (1977).
[3] F. J. Stauffer and D. A. Boyd, Bull. Am. Phys. Soc. 22, 1193 (1977).
[4] G. P. Tait and D. A. Boyd, Bull. Am. Phys. Soc. 22, 1141 (1977).

HIGH POWER LASER AND LOW NOISE RECEIVER FOR SUBMILLIMETER THOMSON SCATTERING ION TEMPERATURE DIAGNOSTIC.*
P. Woskoboinikow,H.C. Praddaude,D.R. Cohn-MIT,Francis Bitter National Magnet Laboratory+, and H.R. Fetterman, P.Tannenwald, B. Clifton -MIT, Lincoln Laboratory.--
The Following submillimeter laser and receiver requirements have been established for the Thomson scattering ion temperature measurement;1) 1MW laser pulses of 200 nsec or longer with a full 10 db spectral bandwidth less than 100 MHz and negligible amplified stimulated emission background;2) overall single sideband(SSB)receiver noise temperature of 7,000K and a bandwidth of 2-5 GHz. The receiver noise temperature will scale up if more laser power is available. The status of the work at MIT is the following;a) the laser parameters have been individually demonstrated for the optically pumped D_2O laser operating at 385 μm; high laser efficiency and narrow linewidth are dependent on a tunable, high power, single mode CO_2 laser pump;b) a receiver has been constructed with a measured SSB mixer noise temperature of 16,000 K, SSB conversion loss of 46, and the required bandwidth. Further work is in progress.

* Work supported by the Department of Energy.
+ Supported by the National Science Foundation.

A Submillimeter-Laser Polarimeter for the Measurement of Faraday Rotation in a Plasma. D. P. HUTCHINSON, K. L. VANDER SLUIS, C. H. MA,* and P.A. STAATS, Oak Ridge National Laboratory[+]--A high-speed submillimeter-laser polarimeter is described. Theory predicts that the poloidal magnetic field and thus the current density of a tokamak plasma can be determined by directing a submillimeter-laser beam through the plasma and measuring the rotation of the polarization. The polarization of the input beam was modulated at a frequency ω_m of 9 kHz-1 MHz. The output beam was passed through a wire grid polarizer in crossed orientation with the initial polarization. For small modulation, the amplitude of the output signal at ω_m was directly proportional to $\theta_m \mathrm{Sin}(2\theta_p)$, where θ_m is the amplitude of the modulation angle and θ_p is the angle of Faraday rotation in the plasma. A ferrite polarization rotator, driven by a pulse current to simulate the rotation in a plasma, was used in calibrating the system. Polarization sensitivity of 26 mV/mrad was achieved for a 4-mW 393-μm FIR laser at a θ_m of 149 mrad. Time resolution of the order of milliseconds was also demonstrated.

*University of Mississippi, University, Mississippi 38677
+Operated by Union Carbide Corporation for the Department of Energy

<u>Development of Beam Dumps for Submillimeter-Laser Scattering Experiments</u>. P. A. STAATS, D. P. HUTCHINSON, K. L. VANDER SLUIS, and D. M. THOMAS,* <u>Oak Ridge National Laboratory</u>[+]--Ion-temperature measurements of high-temperature plasmas will require both laser and viewing dumps with rejection ratios of greater than 10^4. An ellipsoidal reflecting system was developed to measure the reflectivity of beam-dump materials and configurations in the submillimeter range. A cone geometry provides a light trap whose effectiveness depends upon the material reflectivity and absorption. Conical beam dumps made from Lucite, flint, and Pyrex glass with a 10:1 length-to-width ratio were measured as having the required rejection ratio.

*University of Texas, Austin, Texas 76019

[+]Operated by Union Carbide Corporation for the Department of Energy

<u>A One-Megawatt D_2O Oscillator-Amplifier System</u>. K. L VANDER SLUIS, P. A. STAATS, and D. P. HUTCHINSON, <u>Oak Ridge National Laboratory</u>*--A submillimeter-laser source for an ion-temperature diagnostic of a high temperature plasma has been constructed. The oscillator-amplifier system, optically pumped by a 150-J TEA CO_2 laser, produced a power of one megawatt, which was obtained by extending the amplifier pathlength 5 m. The pulsewidth (FWHM) of 100 ns, with a total energy of 100 mJ, exhibits a smooth shape similar to pulses with bandwidths measured to be less than 5 MHz. Detailed measurements of spectral purity are underway. The laser appears to be operating as a pure Raman, two-photon laser at low pressure (1 torr) and as a mixture of a Raman and a normal transition laser at high pressure (5 torr).

*Operated by Union Carbide Corporation for the Department of Energy.

FIR Lasers for Plasma Diagnostics* A. Semet, N.C. Luhmann, Jr. and W.A. Peebles UCLA and D.T. Hodges, F. Foote and R.D. Reel Ivan A.Getting Lab, Aerospace Corp.-- Design stability and mode purity of 50-100 mW cw lasers for interferometry in the 100-500 μm range is discussed. Quasi-cw FIR lasers producing peak powers of ≈ 1W for a fraction of a millisecond should find application as stable local oscillators in low noise receivers for FIR scattering diagnostics. Progress is also reported in the development of a MW-level narrow line FIR laser for ion temperature determination.

*Work supported by NSF-ENG and DOE-DMFE

<u>CW FIR Laser Scattering from Driven Ion Acoustic Waves</u>.*W.A. Peebles, A. Semet and N.C. Luhmann,Jr. <u>UCLA</u>, Th. de Grauuw <u>European Space Agency</u> and J. Gustincic <u>Consulting Engineer</u>. The recent advances in far-infrared (FIR) laser and receiver technology permit the study of spatially resolved density fluctuations by large angle collective scattering.To demonstrate the present feasibility of this technique, scattering of 800 μm radiation was performed from driven ion acoustic waves ($f \simeq 140$ kHz) $\lambda = 1.5$ cm) in an unmagnetized plasma ($n_e \simeq 10^{10}$ cm^{-3}, $T_e \simeq 3eV$, $T_e/T_i \simeq 8$). Density fluctuations as low as $2 \times 10^7 cm^{-3}$ were easily detected. Presently, these measurements are being repeated at 447 μm in addition to scattering from driven electron plasma waves.

*Work supported in part by NSF Grant (ENG-75-14452) and in part by US ERDA Contract E(11-1) Gen. 10 PA26.

A Multichannel Electron Temperature Diagnostic for Tokamaks Using Cyclotron Radiation* G. D. TAIT and D. A. BOYD, Univ. of Maryland--A five channel grating polychromator has been constructed to analyze radiation emitted by the PLT plasma at $2\omega_{ce}$. The instrument looks inwards along a major radius, and each channel sees plasma at a different radial position. Since the plasma is optically thick for extraordinary mode $2\omega_{ce}$ radiation, the signal from each channel is directly proportional to the electron temperature of a small region in the plasma. Radial resolution (set by spectral resolution) of better than 3 cm with a channel spacing of 5 cm has been achieved. Viewing optics restrict the transverse extent of the volume observed. The Putley detectors have an intrinsic response time of less than 1 μs. This system has been used to observe the magnitude and radial variation of electron heating produced by neutral beam injection, and used to follow the T_e fluctuations associated with MHD activity, sawtooth oscillations, disruptions, etc. The cooperation of the PLT group is gratefully acknowledged.

*Research supported in part by NSF and DOE.

<u>Swept-Heterodyne-Cyclotron Emission Receiver Measurements of the Electron Temperature Profiles in PLT.</u>* V. ARUNASALAM, P. C. EFTHIMION, and J. HOSEA, <u>Princeton University</u>. -- The black-body condition for the fundamental cyclotron emission is satisfied in PLT and hence heterodyne detection of this emission provides time-resolved measurements of the electron temperature.[1] Presently, with the local oscillator swept (70-90 GHZ) and feedback stabilized, our microwave radiometer can ascertain the electron temperature profile every 15 ms during the entire discharge. This technique is used to study the time evolution of the electron temperature profiles during both co- and counter neutral beam injection in PLT.

1. J. Hosea et.al., Phys. Rev. Lett., <u>39</u>,408(1977).

*Work supported by U.S.D.O.E. Contract EY-76-C-02-3073.

Ordinary-Mode Fundamental Cyclotron Emission in PLT.* P. C. EFTHIMION, V. ARUNASALAM, and J. HOSEA, Princeton University. -- We present the first experimental evidence for black-body-ordinary-mode fundamental cyclotron emission from a tokamak when viewed from the outside of a torus. This result is consistent with recent theoretical considerations of fundamental cyclotron emission that include finite Larmor radius effects.[1,2] Electron temperature profiles obtained by a microwave heterodyne radiometer measuring the ordinary-mode fundamental cyclotron emission are found to be in good agreement with Thomson scattering profiles and hence this emission is especially important in determining the electron temperature profiles in high-temperature reactor-size tokamaks. These measurements lend significant support to the use of ordinary-mode fundamental electron cyclotron resonance heating (ECRH) of hot plasmas ($T_e \gtrsim 1$ KeV) from the low B field side of tokamaks.

1. I. Fidone et al, Fontenay-aux-Roses, France: Association Euratom-C.E.A., 912, August 1977.
2. T. Antonsen and W. M. Manheimer, Bull. Amer. Phys. Soc., 22, 1186 (1977).

*Work supported by U.S.D.O.E. Contract EY-76-C-02-3073.

<u>Tokamak Synchroton Radiation Measurements Using Conventional and Quasi-Optical Schottky Diode Heterodyne Receivers.</u>* N.C. Luhmann, Jr., W.A. Peebles, and A. Semet, <u>UCLA</u>, Th. de Grauuw <u>European Space Agency</u> and J. Gustincic <u>Consulting Engineer</u>.--Measurements of the electron cyclotron emission from the UCLA Microtor/Macrotor tokamak devices have been performed using both conventional and quasi-optical Schottky barrier diode receivers at a series of wavelengths well into the submillimeter region ($\lambda \geq 0.4$mm, $\omega/\omega_{co} \leq 30$). These sensitive radiometers (NEP $\leq 3 \times 10^{-19}$ W/HZ) permit high frequency resolution ($\Delta f/f \leq 10^{-2}$) measurements with fast time response (Γ<20nsec). The effects of ICRH and lower hybrid heating on the spectrum will be discussed.

*Supported in part by NSF Grant (ENG-75-H452) and in part by US ERDA Contract E(11-1) Gen. 10 PA26.

Radiometric Measurements of T_e on Doublet IIA.* JOHN LOHR and R. K. FISHER, General Atomic Co.--A superheterodyne radiometer operating at 2 ω_{ce} has been installed on Doublet IIA. The instrument covers 33 - 75 GHz in two bands and can be swept repetitively over the entire frequency range in less than 2 msec. The primary calibration is by Thomson scattering with secondary calibration to a 1 eV argon discharge tube. Evidence for a suprathermal tail on the electron distribution is seen on discharges which produce hard X-rays. Effects of disruptions and sawtooth oscillations on the temperature profile have also been observed. A spatial asymmetry in the measured profiles is attributed to absorption at the upper hybrid frequency.

*Supported by Department of Energy Contract EY-76-C-03-0167, Project Agreement 38.

Temporal Variation of T_e in LITE.* J.H. STUFFLEBEAM, United Technologies Research Center--Microwave emission propagating in the extraordinary mode at 33 GHz is monitored throughout the plasma decay in the LITE experiment to yield information of the relative change in electron temperature. The radiometer is calibrated by Thomson scattering measurements to yield the temporal variation of electron temperature. The observed frequency corresponds to the electron cyclotron frequency at the center of the minimum-B, mirror-confined plasma, ($\frac{\omega_c}{\omega} \sim 1$); and $0 \leq \frac{\omega_p}{\omega} \leq 1$ as the density decays. Significant variation of electron temperature with the presence of the DCLC instability is observed. This correlation impacts directly on current experiments in mirror confinement and stabilization.

*Supported in part by U.S.D.O.E. Contract EY-76-C-02-2277.*000.

Collision Effects on Light Scattering by Plasmas Containing Ionized Impurities. O. THEIMER, and A.N. SANDALOV*, New Mexico State U.--A high temperature deuterium plasma is considered containing fully ionized impurities, e.g., 2% oxygen with charge q_0=8e. Evans' collision free treatment[1] of such systems is generalized to include collisions, and it is shown that, due to the large charges involved, collision effects are not negligible, since the collision frequency for encounters between particles with charge q and q' is proportional to $q^2q'^2$. A general theory of light scattering by many-component plasmas containing ionized impurities is presented, with special emphasis on the structure of the "ion line". Approximate analytical expressions for the light scattering spectrum are discussed and numerical results are presented which show the significance of collision effects for various diagnostic problems such as the electron and ion temperature, the charge, mass and density of impurities, and turbulence.

*On leave from the University of Moscow, USSR
[1]D.E. Evans, Plasma Physics 12, 573 (1970).

<u>Development of Diagnostic Techniques for ALVAND-2 Tokamak.</u> *R. Aghevli, M. Amini-Rad, M. Avakian, H. Azodi M. Naraghi, B. Rezvani, and M.H. Tabatabai. <u>NRC, Atomic Energy Org. of Iran.</u>-- The ALVAND-2 Tokamak program is aimed at the development of diagnostic techniques with potential use for larger tokamaks. Various diagnostics that are being developed include probe techniques, microwave interfermetry , and laser scattering. Soft X-ray intensity and spectra measurements will also be made. Microwave fringe-shift interferometry is achieved through the use of circuitry that includes a hybrid mixer, two square-law detectors, and a differential amplifier along with a digitizer and a processor so as to be able to read the average density directly after each shot. A pulsed Q-switched ruby laser is used for electron temperature measurement in a Thomson scattering experiment. An experiment that employs the intermediate scattering domain will be attempted for the purpose of an independent electron density measurement. The various diagnostic measurement apparatus, set-ups, and techniques will be described.*

THE SANDIA LABORATORIES DIAGNOSTIC SYSTEM FOR PARTICLE BEAM FUSION EXPERIMENTS*

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ABSTRACT

A review of diagnostics used at Sandia Laboratories to measure target performance in the particle beam fusion program will be presented. These diagnostics consist of several types, namely: (1) X-ray pinhole photography with computer image enhancement, (2) coded zone plate X-ray imaging, (3) velocity interferometry, (4) time resolved four-pulse optical holography, (5) X-ray flash radiography, (6) X-ray spectroscopy, and (7) neutron diagnostics. These components when taken together enable a thorough description of target dynamics. In particular, the diagnostics are capable of measuring irradiation symmetry, energy deposition, ablator dynamics, implosion physics, and neutron yield of a target. A unique feature of these diagnostics is that implosion dynamics, including the effects of Rayleigh-Taylor and other fluid instabilities, may be directly observed. A feature of the neutron diagnostic system is the use of heavily shielded high-current scintillator photomultiplier combinations to make neutron time-of-flight measurements in a X-ray Bremsstrahlung background of some 10^{9}-10^{10} Rad/sec. Possible future upgrades of this set of diagnostics will also be discussed.

*This work was supported by the U. S. Department of Energy, under Contract AT(29-1)-789.

Recent X-Ray Analysis of Laser-Fusion Plasma.*

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Spatial, spectral, and temporal resolution of x-rays emitted from dense, highly excited matter is of primary interest throughout the laser-fusion community. Two types of x-ray diagnostics of current interest will be presented. The nature of the imploded core of DT, DT/neon and pure neon filled glass microballoons driven by two beams, 250 J per beam, and 1 1/2 ns FWHM pulse length CO_2 laser light has been studied. Compression of the microballoons has been observed with spatially resolved crystal spectrometers sensitive to x-ray lines. The spectrometer slit widths ranged from 20 μm to 60 μm and the crystals used in these experiments were TAP, PET, and EDDT. The hydrogen-like and helium-like neon lines from microballoons filled with DT-neon mixtures and pure neon show clearly the region of high compression. The spatial extent of the neon emission region together with an analysis of Stark broadening and self absorption of the observed lines yields neon densities from 10^{20} atom/cm^3 to 10^{21} atom/cm^3 or a compression of 30 from the original gaseous state. Another diagnostic that has received wide interest recently is the fast, soft x-ray sensitive, photoelectric diode (XRD). Two different versions of this type of detector have been built at LASL. The first detector is a four channel miniature XRD array with a temporal resolution of 650 ps incorporating four aluminum photocathodes in a standard vacuum flange with various filter window anodes to achieve energy selective response in the sub-keV x-ray regime. The second detector is a fast single element detector in a simple coaxial 50 Ω geometry with a risetime of 75 ps. For glass microballoons, the x-ray spectral below 150 eV have a sharp rise and last from 4 ns to 5 ns; however, x-rays near an energy of 270 eV have a temporal extent of only 1/2 ns to 3/4 ns. Time integrated x-ray spectra from 30 eV to 88 keV have been obtained with XRDs covering the 30 eV to 270 eV spectral region; K-edge filters in the 400 eV to 4 keV region and at 88 keV; Bragg crystal spectrometer covering the 5 keV to 33 keV range. Highlights of results from other laboratories will also be discussed.

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*Work performed under the auspices of the U. S. Energy Research and Development Administration

Plasma Physics Experiments On A Scale of Microns and Picoseconds*

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Abstract

Laser driven fusion involves the heating and compression of small hydrogen filled capsules to thermonuclear conditions. Current experiments typically focus intense 100 psec laser pulses on 100 μm diameter targets. Diagnostic requirements are best understood in terms of several distinct regions, the low density plasma atmosphere surrounding the target where laser light is absorbed, the high density exploding shell which drives the implosion, and the encapsulated fuel itself. In this paper we review selected diagnostic techniques used to characterize the various regions, and draw conclusions concerning dominant processes in each. Interferometry, resolved to 1 μm and 15 psec, is used to measure electron densities in the plasma atmosphere. From that data it is evident that laser radiation pressure plays a significant role in steepening density profiles, therefore impacting the processes through which laser light is absorbed and energy transported to the imploding shell. The imploding shell itself is observed through its own x-ray emission with a combination x-ray pinhole/streak camera, allowing us to track the implosion velocity with a combined resolution of 6 μm and 15 psec. Final implosion velocities of 3×10^7 cm/sec and average accelerations of 3 to 4×10^{17} cm/sec^2 are recorded. Comparison of the measured implosion history with numerical simulations suggest that energy transport from the plasma atmosphere to the ionized shell is inhibited. Recent work by Ceglio, with zone plate coded imaging, provides 3 μm resolution α-particle images of the thermonuclear burn region, confirming the overall success of these experiments.

*Work performed under the auspices of the U.S. Department of Energy under contract No. W-7405-Eng-48.

Physics and Application of Secondary Electron Emission from X-Ray Photocathodes. B. L. Henke, U. of Hawaii--Most of the electrons which are ejected from a solid that is exposed to an x-ray beam appear as secondary electrons with kinetic energies less than 10 eV and with a relatively sharp energy distribution of FWHM values less than 5 eV. This secondary electron "signal" can be the basis for the measurement of the intensity and the temporal history (into the picosecond range) of x-ray sources. For example, x-ray photocathodes are currently applied in diode detectors and in streak and framing cameras. Simple models have been developed for the prediction of the shape and for the total yield of the secondary electron distribution as these depend upon the x-ray photon energy and upon the x-ray absorption and solid state characteristics of the photocathode. To test these models, the secondary electron distributions and relative quantum yields have been measured for selected photocathode materials (metals, semiconductors and insulators). Several alkali halides have been found to have much higher quantum yields and appreciably narrower energy distributions than do metal photocathodes such as aluminum and gold for the x-ray photon energy region of 0.1 to 10 keV. The shape of the secondary electron distributions are essentially independent of photon energies in this region. The experimental results have been found to be in good agreement with the the model predictions.

<u>Ultrasoft X-Ray Calibration of X-Ray-Diodes For Laser Fusion Plasma Diagnostics</u>.* R. H. DAY, P. LEE, T. L. ELSBERRY, <u>Los Alamos Scientific Laboratory</u>, E. B. SALOMAN, <u>National Bureau of Standards</u>, and D. J. NAGEL, <u>Naval Research Laboratory</u>--We have developed an ultrafast, soft X-ray sensitive, photoelectric diode (XRD) for use in diagnosing laser fusion plasmas. It is a single element detector with interchangeable photocathodes in a simple coaxial 50 Ω geometry with a measured 10-90% risetime of 50 ps and an RC decay time of 65 ps. The X-ray sensitivities of this detector have been measured from 500-50Å using the synchrotron radiation facility at the National Bureau of Standards and from 45Å to 1Å at the Henke X-ray facility at Los Alamos Scientific Laboratory. Cathodes of C, Al, Ni, Cu, and Au were used.

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*Work performed under the auspices of U. S. Department of Energy.

Fast, Large Signal, Free Standing Foil Bolometer for Measuring Ultrasoft X-Ray Burst Fluence - J.H. Degnan, M.C. Clark, R.E. Reinovsky, G.F. Kiuttu, G. Kahn.--A fast ($\sim$ 300 nanosecond), large signal $\gtrsim$ 1V.), free standing foil bolometer was developed for measuring ultrasoft X-ray burst fluences. The results of bolometer measurements of the radiation output of an imploding foil liner plasma indicate yeilds of several tens of kilojoules, assuming isotropic emission. This is in substantial agreement with filtered metal photocathode (X-ray diode) measurements. The bolometer design, response function, and comparison with X-ray diode data will be discussed.

<u>A Twin Pendulum Device for Plasma Diagnostics</u>. B. ARAD, S. ELIEZER, Y. GAZIT, H.M. LOEBENSTEIN, M. ROSENBLUM, A. ZIGLER, H. ZMORA, and S. ZWEIGENBAUM, <u>Soreq Nuclear Research Center, Yavneh, Israel</u>.--Thin foil aluminum targets were irradiated by a Nd:glass laser beam. The momentum of the plasma produced was measured by a recently designed twin torsion pendulum set-up. These measurements have confirmed the 3/4 power law for moderate laser intensities as derived by dimensional analysis assuming inverse bremsstrahlung absorption and neglecting lateral heat conduction. In addition we show that the calculated burnthrough time based on those measurements agrees with the measured one using X-ray PIN photo-diodes. This agreement proves the usefulness of the twin torsion pendulum device for plasma diagnostics. Moreover, this pendulum device is useful in detecting the presence of non-linear absorption processes.

Investigation of the Transient Regime of Laser Produced Plasma by Space Resolved X ray Spectroscopy.

A. ZIGLER, H. ZMORA, H.M. LOEBENSTEIN, and J.L. SCHWOB, Soreq Nuclear Research Center, Yavneh, Israel.--The spatial and temporal behaviour of the x ray emission from laser produced aluminum plasma was deduced from space resolved x ray spectroscopy and a comparison between x ray spectra observed from both sides of thin (1-10μm) Al foils. The Li, He and H like ion species were found to have different spatial and temporal behaviours. The evolution of the plasma from the ionizing stage to steady state is also followed. The meaning of electron temperature values deduced from various spectral line ratios is also discussed.

<u>X-Ray Image Intensifier</u>. R. E. McDonald, Lockheed Palo Alto Research Laboratory. *----A high-resolution x-ray image converter has been built with resolution > 100 lines mm^{-1} for laser-focus plasma x-rays. Electrons from a beryllium-supported gold cathode are accelerated to energies ≤ 50 keV and magnetically focussed on a ZnS screen coupled to a commercial image intensifier tube. The system is readily demountable and magnification may be varied from 5 to 20. Streaking plates after the magnetic lens make the device useful as an x-ray streak camera. Images of laser-focus plasmas will be shown in both static and streaked modes.

*Supported by the Lockheed Independent Research Program.

Space Charge Effects in Laser Plasma Particle Diagnostics.* STEVEN J. GITOMER and HENRY BRYSK, Los Alamos Scientific Laboratory. --In laser plasma particle diagnostics, the plasma incident upon the various measuring instruments is delimited by a narrow pinhole or aperture. Typical Debye lengths (1 micron to 1 mm) can be comparable to the size of the pinhole in particle detectors. Thus, single particle effects may be important. In particular, we consider the possibility that, because of an image force within the aperture, the plasma will issue from the aperture with a net charge. This charged beam would then be subject to space-charge spreading due to its own electric field. We treat both aspects of this problem in an approximate analysis. We apply our results to recent ion pinhole measurements to show that space charge effects can account for otherwise puzzling features of the data obtained.

* This work was performed under the auspices of the United States Department of Energy.

An Electrostatic, Ion/Electron Spectrometer For Laser-Produced Plasma Measurements.† D. WOODALL†† and C. SHAFFER, Univ. of New Mexico--A multichannel spectrometer has been designed, constructed, and tested as a diagnostic instrument for laser-produced plasmas. This is the first report of a spectrometer for simultaneously recording the high energy electrons and ions from such a plasma. The device provides considerable resolution for ions (10 channels) and electrons (3 channels) between 1 and 100 kev. An electrostatic field (up to 500 kv/m) between parallel plates deflects a plasma beam incident through the lower plate at 30° into electron and ion components. Exit slits in the upper plate accommodate electrons and energetic ions, while ions of lower energies exit through slits in the lower plate. All signals are recorded at copper Faraday surfaces with transverse magnetic field suppression of secondary electrons. The device is being tested on the Sandia single-beam Nd-glass laser system, with > 50J at 1.06 μ incident on planar metal targets with a pulse width of < 10 nsec.

†Work supported by the Department of Energy through Sandia Laboratories. ††Consultant for Sandia Labs.

Soft X-Ray Diagnostics of CO_2-Laser-Heated Magneto-Plasma,* N. G. LOTER,+ W. HALVERSON, C. V. KARMENDY,+ MIT, Francis Bitter National Magnet Lab.‡- Soft x-ray diagnostics are used to study plasma generated by gain-switched CO_2 laser pulses of up to 300 J and partially confined by dc magnetic fields up to 105 kG. Planar solid target materials include graphite and teflon (CF_2). X-ray pinhole photographs show two components: a brigt region of about 100 μm width along the target surface, and for fields greater than 50 kG a diffuse column extending back toward the laser, parallel to the magnetic field. An x-ray collimator shows this column to reach lengths in excess of 15 cm by the end of the 1 μsec laser tail. Electron density and temperature of the confined plasma are measured with a TAP crystal soft x-ray spectrometer observing lines from helium-like ions and associated satellites. Electron temperature is also measured from x-ray continuum[1] and inferred from Brillouin backscatter. Results are consistent with β being near unity during the tail of the pulse.

*Supported in part by AFOSR.
+Also Physics Department, MIT.
‡Supported by the National Science Foundation.
1W. Halverson and C. V. Karmendy, J. Appl. Phys. 48, 99 (1977)

<u>X-Ray Spectra of Vacuum Spark Plasmas</u>. T. N. LEE, J. F. SEELY* and R. C. ELTON, <u>Naval Research Laboratory</u>--The np→1s transition lines ($2 \leq n \leq 6$) of highly ionized Ti through Ni have been observed with time and space resolution using a simple flat LiF crystal spectrometer. A single-discharge exposure enables determination of spectral features emitted by an individual point plasma. A computer model is used to calculate the intensities of the np→1s transition lines of the He- and H-like ions. Doubly excited satellite lines of the He- and Li-like ions are included. Population densities of the n,ℓ states ($n \leq 10$) of the H-like, He-like (singlets and triplets), and Li-like ions are calculated, with opacity included. From the best fit to the experimental intensities, the electron temperature, electron and ion densities, excited state population densities and optical depth are inferred, with the intention of improving the accuracy of previous values deduced from broadband measurements.

*NRC-NRL Resident Research Associate

Determination of the Size of the X-ray Line Emitting Point Source.* R. U. DATLA, Department of Physics, University of Maryland, College Park, MD 20742. --It is shown theoretically that the size of a point source of x-ray line emission could be determined by recording the line spectrum using at least two analyzing crystals of different dispersions. Measurement of the source size is very much needed for analyzing the various contributions to the x-ray line profile especially for determining the stark contribution in spark[1] or laser produced plasmas. The underlying principle is that each x-ray analyzing crystal projects only a geometric image of the source which is independent of its dispersion. As an experimental verification, results from an experiment using an x-ray tube with various pinholes kept in its front and an x-ray flat crystal spectrometer at different dispersions are presented.

*Supported by National Science Foundation.
[1]R. U. Datla and H. R. Griem, Phys. Fluids (to be published).

Line and Continuum Radiation as a Liner Implosion Diagnostic. L. J. SUTER, D. M. KRAYBILL, I. R. LINDEMUTH and J. C. STEVENS, Lawrence Livermore Laboratory.*--Calculationally, liner implosions appear to produce plasmas which may have large temperature and density gradients. While neutron production can be used to diagnose the hottest regions, some other technique must be employed to study cold dense regions which may form near the walls. Such regions, which often appear to be a key feature of the plasma dynamics during an implosion, may be diagnosed spectroscopically. We report here predictions of the hydrogen continuum radiation as well as carbon line radiation for several idealized liner implosions as calculated on the ANIMAL code[1]. We shall indicate which spectral regions would most profitably be used to normalize the code and consequently lead to detailed understanding of the plasma physics of the implosion.

[1] I. Lindemuth, Proceedings of the Annual Meeting on Theoretical Aspects of CTR, Roslyn, VA, April, 1975.

*This work performed under the auspices of the U.S. Department of Energy under contract No. W-7405-Eng-48.

Measurements of Field Reversal with a One-Turn Loop Encircling the Plasma. J. D. SETHIAN, K. A. GERBER, D. N. SPECTOR, and A. E. ROBSON, N.R.L.--A rotating relativistic electron beam, injected along a 2.6 kG guide field, fully ionizes an initial filling of neutral hydrogen (n_e=5.5X10^{15}cm^{-3}) and induces azimuthal plasma currents of sufficient magnitude to reverse the applied field on axis. The induced axial field, ΔB_z, can be inferred from the voltage measured across a one-turn loop encircling the plasma by using a simple flux conservation model and the plasma radius observed with streak photography. The ΔB_z indicated by this loop agrees well with that indicated by a miniature local magnetic probe positioned on axis. However, as such a probe perturbs the beam-plasma system, resulting in lower ΔB_z values and faster decay times when this probe is in place, the primary diagnostic for determining ΔB_z is the one turn loop.

CO_2 LASER SCATTERING

C. M. SURKO

Bell Laboratories, Murray Hill, N.J.

Density fluctuations in plasmas can have important physical consequences such as the enhanced transport of particles and energy. Study of the small-angle scattering of CO_2 laser radiation using heterodyne detection provides detailed information about the wavevectors, frequencies, and amplitudes of these density fluctuations.[1-3] This technique is useful over a wide range of plasma densities from 10^{10} to 10^{19} cm^{-3}, and typically requires only a small angular access to the plasma ($\theta \lesssim 1°$). The essential features of this technique will be discussed. A new technique[2] will be described which utilizes the correlation of scattering from two crossed CO_2 laser beams to study the spatial distribution of density fluctuations in plasmas. To exemplify the use of these techniques in fusion plasmas, studies of density fluctuations in the ATC and ALCATOR tokamaks will be described. The implications of these results, including the changing nature of the fluctuations as a function of plasma density, will be discussed. The use of pulsed lasers to measure ion temperature[3] will also be discussed.

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[1] C. M. Surko and R. E. Slusher, Phys. Rev. Letters 37, 1747 (1976), and references therein.

[2] R. E. Slusher and C. M. Surko, Bull. Am. Phys. Soc. 22, 1091 and 1092 (1977), and to be published.

[3] A. Gondhalekar and E. Holzhauer, Phys. Lett. 51A, 178 (1975); D. R. Baker, N. R. Heckenberg, and J. Meyer, IEEE Trans. Plasma Sci. PS-5, 27 (1977); and A. L. Peratt, R. L. Watterson, and H. Derfler, Phys. of Fluids 20, 1900 (1977).

Heterodyne Interferometry.* R. KRISTAL, Los Alamos Scientific Laboratory. (30 min.)

In heterodyne interferometry the plasma density variation is observed as a phase distortion of the beat (heterodyne) signal between two optical beams of different frequencies. The virtues of the technique include self-calibration, fractional fringe resolution over a multi-fringe range and unambiguous sense determination. Recent developments, due largely to the introduction of acousto-optics, have resulted in new and exciting extensions of the technique. By using a Bragg cell to split the source laser beam, frequency shifts of over 100 MHz are readily generated between scene and reference beams. Thus, time resolution in the 1 nsec range is possible, permitting the use of the technique for investigating shocks and other high speed phenomena. For applications where the full time resolution of the ultrasonic frequency is not required, the rf source provides a useful reference signal for electronic phase comparison with the heterodyne signal, and a variety of techniques may be used to give real or semi-real time output. Phase resolution of 0.01 - 0.1 fringe is possible for bandwidths in the range 1 - 100 MHz. The most significant development in heterodyne interferometry, however, is the application to density profiling. By combining heterodyne interferometry with rapid spatial scanning, the temporal (heterodyne) fringes are converted to spatial fringes. By making the scan time short enough to "freeze" the plasma, multiple density profiles can be obtained during a single discharge using a single detector channel. As an example, a near IR system (3.4 μm) designed for pinch plasmas uses a high speed rotating mirror scanner (0.5 million rpm) and 100 MHz heterodyning. It produces 25 resolution spots in 1/4 μs with better than 0.1 fringe (3×10^{15} elec/cm^2) phase resolution. The basic idea is applicable over a wide portion of the IR spectrum and therefore is useful even for rather tenuous plasmas. Excellent spatial and phase resolution are possible, being largely a function of wavelength and scan time. This is of prime significance in those cases where Abel inversion is required.

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*Work performed under the auspices of U. S. Department of Energy.

Trends in Data Acquisition -- Systems Which Wear Well

by

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The development of standards such as the HP-Bus and CAMAC makes possible data acquisition systems which can evolve from today's experiments to tomorrow's comprehensive data retrieval and analysis systems. Processors are available to interface with these standard modules, to perform control and computation at various levels of complexity (and funding). Such a system is evolving at General Atomic, among other places, with careful attention paid both to meeting the basic requirements of the initial user(s) and to incorporating the "hooks" for future more varied and sophisticated applications. Both the hardware and computer programs in such a system must be carefully designed initially to insure that they may be expanded modularly, without the need to rework or cast aside large portions of them.

Work supported by the U. S. Department of Energy under Contract EY-76-C-03-0167, Project Agreement No. 38.

A Doubled Nd-Glass Laser System for Low Density Incoherent Thomson Scattering. *B. A. Jacoby, T. M. York, and R. A. Mollo, The Pennsylvania State University.--Conventional Thomson scattering using a ruby laser evidence difficulty in scattered signal detection as plasma densities drop to $10^{12}cm^{-3}$. Studies of θ-pinch endloss flow can require density resolution in the range. Use of a Nd-Glass laser as a source and frequency doubling the output can increase the incident energy and quantum efficiency of the detectors such that gains in scattered signal of greater than an order of magnitude over a conventional ruby laser system can be achieved. Due to the ~25Å bandwidth of the Nd-Glass laser line, however, the electron temperature information in the incoherent scattered signal must be extracted from a Voigt Profile, not from the usual Gaussian profile as when a ruby laser is used. The details of the above are to be described.

*Work performed under the auspices of the U.S. Energy Research and Development Administration.

The Measurement of Magnetic Fields in Tokamaks by the Detection of the Cyclotron Modulated Scattered Laser Light Spectrum. M. J. FORREST, P. G. CAROLAN, N. J. PEACOCK, Culham Laboratory, Abingdon, Oxon, UK, (Euratom/UKAEA Fusion Association).--A new laser light scattering technique has been used to determine the local magnetic fields in the Culham DITE Tokamak[1]. This technique depends on the sensitivity of the cyclotron modulation of the scattered spectrum to the angle between the local magnetic field and the plane in which the scattered light is detected. Novel optics that detect the plane containing the modulated spectrum, magnify the pitch of the magnetic field lines and provide a spatial scan are described. First results show the pitch angle can be determined to within 0.15^{o} (equivalent to Δ_q of 5%) with a spatial resolution of ± 2 mm. The poloidal field distribution $B_\theta(r)$ corresponds to the measured plasma current and the derived q(r) profile agrees with that calculated from the T_e profile. A brief indication of the suitability of the technique for similar measurements on large Tokamaks, such as JET, is given.

[1]J. W. M. Paul et al. Proc. of 6th IAEA Conference on Plasma Physics and Controlled Fusion Research, Berchtesgaden, Vol. 2, 269 (1976).

Scattering with Periodically Pulsed YAG-Lasers for Time-resolved T_e- and n_e Measurements. H.F.DÖBELE, K.HIRSCH, E.HOLZHAUER, R.REISCHL, Stuttgart Univ.-- The advantages of periodically pulsed lasers for time resolved scattering diagnostics are discussed[1]. CW-pumped YAG-lasers with an internal modulator produce pulses of 100-500 ns duration in the kHz range. Detectors are cooled IR-photomultipliers or Si-avalanche diodes. These diodes can only be used, if their capacitance is largely compensated to overcome amplifier noise. A first experiment used a low-power YAG-laser (6 W, 2.5 kHz, 200 ns pulse-width) and a compensated Si-diode. Scattered spectra from a H_2-arc plasma ($n_e = 1 - 5 \cdot 10^{15} cm^{-3}$, $T_e = 1 - 2.5$ eV) were obtained for $\alpha = 0.3 - 1$ ($\theta = 90°$). The application of this method to measure continuously parameters of tokamak-type plasmas with millisecond time-resolution is discussed.

[1] H.F.Döbele, M.v.Hellermann, K.Hirsch, IPF-Report 77-5, Inst. f. Plasmaforschung, Univ. Stuttgart, 1977

Forward Scattering at 10.6μ using Heterodyne Detection to measure Ion Temperature. E.HOLZHAUER, J.H.MASSIG, Stuttgart Univ. --Light mixing techniques at 10.6μ were used to scatter at small forward angles[1] (θ = 28 - 38 mrad) from a H_2-arc plasma ($n_e = 1\text{-}5\cdot 10^{15}$ cm^{-3}, T_e = 1-2.5 eV). The spectrally resolved ion feature of the plasma has been obtained in a pulsed and in a stationary measurement. For the pulsed experiment a TEA-hybrid-laser of high mode purity was used (T=1 μs 200 kW). The complete spectrum could be obtained in one shot by Fourier analysis of the stored signal. In the stationary experiment with a CW-laser (20 W), using lock-in techniques, consistent results were obtained. Calibration and control of the critical adjustement were achieved by scattering from ultrasonic waves in neutral gas. The resolution in real-and k-space was investigated analytically and experimentally[2]. Based on these results the application to tokamak-type plasmas will be discussed.

1 Gondhalekar, A., Keilmann, F., MPI Garching, Report 2/202 (1971)

2 Holzhauer, E., Massig, J.H., Report IPF 77-6, Inst. f. Plasmaforschung, Univ. Stuttgart, 1977

Thomson Scattering Diagnostics For PDX.* C. C. DAUGHNEY, Princeton Univ.--The PDX tokamak experiment at Princeton will include three, ruby laser, Thomson scattering diagnostic systems. The first incorporates a two-dimensional detector and provides electron temperature and density profiles from a single discharge. This system is similar to the PLT diagnostic system which has been described previously.[1]

Two specialized Thomson scattering diagnostics, utilizing photomultiplier detectors, are described in the present paper. One is designed for two-dimensional spatial scan of the non-circular cross section. Special emphasis will be placed on study of plasma parameters along the magnetic separatrix. The other system is designed for maximum sensitivity and gives accurate measurement of electron temperature and density with the possibility of studying the parallel and perpendicular electron velocity distributions. In particular, feasibility of measuring the local electron drift velocity and ion effective charge will be discussed.

*Supported by U.S.D.O.E. Contract EY-76-C-02-3073

1. N. Bretz et al, J. Applied Optics (to be published)

Diagnostics Development For The PCX Laser Heated Solenoid Experiment.* E.A. CRAWFORD, D.D. LOWENTHAL, and A.L. HOFFMAN, Mathematical Sciences Northwest, Inc.--The Laser Heated Solenoid, Proof of Concept Experiment (PCX) has as its objective the demonstration of beam trapping and plasma heating in a high density (3 X 10^{17} cm^{-3}), long (1-3 meter) slender (~5 mm diameter) column. In order to accomplish this it is necessary to measure the time dependent evolution of the density profile and line energy at various axial locations. A moderately unique Mach Zehnder quadrature interferometer, utilizing polarizing optics, has been developed to view the plasma between magnet turns. Integrated density measurements can be made through the plasma tube with 1/40 of a fringe resolution at 632.8 nm. The spatial and temporal resolution are 0.2 mm and 30 nsec respectively. Diamagnetic loops were developed to fit in the 2.5 mm gap between plasma tube and magnet, and yet provide 20 kV voltage isolation. Careful attention to the high frequency behavior of attenuators, differencing elements, and integrators has permitted excluded flux measurements to be made to an accuracy of 0.1 cm-Tesla. Results obtained with these diagnostics will be discussed.

*Research supported by US DOE CONTRACT EY-76-C-06-2319

<u>A multichannel Ruby Laser Scattering Device for the TFR Tokamak*.</u> TFR Group, Association Euratom-CEA, 92260 Fontenay-aux-Roses, France. Paper presented by P. PLATZ. -- Radial electron temperature and density profiles are obtained with a single discharge and laser shot. For each point of a profile there is an individual compact, two-detector, concave-grating spectrum analyzer with two broad wavelength channels, the limits of which are chosen for maximum sensitivity. The temperature range from 0.3 to 8 keV is covered by two switchable modes of operation. The system is fully computer operated.

* Submitted by C. DE MICHELIS, J. Lasalle and P. Platz, Optics Com. 17, 325 (1976) and Rev. Phys. Appliquée, 12, 1181 (1977).

90° CO_2 Thomson Scattering from a Pulsed Hydrogen Arc.* M.J. Herbst and W.A. Peebles, UCLA.- The spectrum of Thomson scattering of a CO_2 laser from a pulsed Hydrogen arc yields the ion temperature, given an experimentally determined electron temperature. Scattering at 90° is observed from plasmas of electron densities $2 \times 10^{15} - 10^{16} cm^{-3}$ and temperature $T_e \simeq T_i$ = 5eV with an 80 nsec FWHM, 70MW laser pulse. The spectrum is resolved on a shot-to-shot basis using a scanned Fabry-Perot of finesse 6 and a liquid-He coded Ge:Hg photoconductive detector. Signal-to-noise ratios for the experiment are limited by electronic amplifier noise. Relevance to diagnostics for fusion plasmas will be discussed.

*Work supported in part by NSF ENG 75-16610, ERDA-DLF E(04-3)-34, PA 36 and ERDA-DMFE E (11-1) Gen. 10, PA 26 Task II.

A Small-Angle CO_2 Scattering System Employing Beam Apodization and Homodyne Detection.* T. ANGEL, P. HUDSON, J. SHLACHTER, and R. LOVBERG, University of California, San Diego--We have developed a small-angle CO_2 laser scattering system that incorporates several novel features useful in research on CTR plasmas: a) a long-pulse E-beam sustained laser, built for this application, delivers 10 kw for 500 μsec, and exhibits low levels of temporal and spatial noise; b) the use of apodization techniques in beam profiling results in great reduction of noise diffracted into angles near the main beam, e.g., 1 milliradian; c) homodyne detection, employing a reference beam scattered from a wire over the main relay mirror, enhances S/N by as much as 10 db; d) an on-line data processing system presents a 1 K-point Fourier transform of the detector output 5 seconds after each shot. The long laser pulse and broad-band detectors allow investigation of temporal fluctuation spectra from 5 kHz to 200 MHz. As presently configured, the apparatus spans the spatial fluctuations wavelength range of 5 mm to 10 mm. The present sensitivity limit is approximately $\Delta n = 10^{10}$ cm^{-3} for unit S/N ratio at 2 mr scattering angle.

*Work performed under the auspices of U. S. Department of Energy under Contract EY-76-S-03-0034 PA221.

Infrared Heterodyne Interferometer for Multichord Plasma Density Measurements.* A. R. JACOBSON, Los Alamos Scientific Laboratory.--An infrared interferometer has been developed for side-on measurements of electron density in a toroidal reversed-field pinch. A Bragg cell is used to frequency-shift the reference beams, and quadrature phase detection is performed on the detected carriers. The output signals are analyzed by computer, for on line analysis of density profiles immediately following the plasma discharge. The present device measures along five chords simultaneously.

*Work performed under the auspices of the U.S. Department of Energy.

<u>Measurements of the Plasma Ablated from an End Plug in a High Energy Theta Pinch using Ruby Laser Side-Viewing Holographic Interferometry</u>.* C. A. Ekdahl, R. J. Commisso, K. F. McKenna, and R. E. Siemon, <u>Los Alamos Scientific Laboratory</u>--A ruby laser double-exposure holographic interferometer has been used to study the interaction of a hot, dense plasma column ($T_e + T_i \sim 2$-3 keV, $n \sim 10^{16}$ cm^{-3}) with solid end plugs inserted to eliminate axially loss of plasma. The holographic technique has made possible the realization of high quality interferograms even though viewing through a poor optical quality quartz discharge tube. Interferometry with ruby laser light (6943Å) across the small plasma diameter ($\sim$ 2 cm) is only possible because of the high electron density (10^{17} - 10^{19} cm^{-3}) associated with the ablated plasma. Radial density profiles obtained by Abel inversion of the interferograms show a peak density on axis of greater than 10^{18} cm^{-3} near the plug surface, however, this profile becomes annular at distances of greater than 2 cm from the surface.

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*Work performed under the auspices of the U. S. Department of Energy.

<u>Measurement of Line Density with a Multi-pass Interferometer</u>.* W. T. Armstrong and G. Miller, <u>Los Alamos Scientific Laboratory</u>--The line density, $n_\ell = \int n dA$, is an important measurement for confinement studies on linear theta-pinch systems. A method for this measurement is described in which a single coherent beam is passed repeatedly across the plasma along different chords. The effective measurement is

$$n_\ell = \int n(r,s)\, dr\, ds$$

$$\simeq \sum_j \Delta r_j \int n(r_j,s)\, ds \ ,$$

where s is along a chord and r is the transverse position of the chord. Beam aberration due to repeated passes through the discharge tube is expected as the main limitation to the technique. Initial investigations of a multi-pass system, using a quadrature interferometer, are reported.

*Work performed under the auspices of the U. S. Department of Energy.

Measurements of Plasma Temperature using Stimulated Brillouin Scattering in a Laser Heated Solenoid, Z.A. Pietrzyk, T. Carlstrom, D.W. Scudder, University of Washington*--The Brillouin backscattered spectrum is shifted from an incident frequency by an ion accoustic frequency. Since $\omega_a = k(\gamma T_i + \gamma_e T_e)$, by measuring the shift of the backscattered radiation the plasma temperature can be measured. In our experiment the energy equipartition time is very short, 30ns, and therefore $T_e \simeq T_i$. This method was checked previously against C_V method[1]. The present experiments have been done in 0.5m solenoid with a 100kG magnetic field. The plasma is created and heated by a 200-500 joule CO_2 laser beam. The backscattered spectrum is recorded by an infrared spectrometer with a 25A° resolution and a HgCdTe detector. The data was taken with a shot-to-shot wavelength scan. The results show the temperature change with time which occurs during laser heating. At later times the temperature drops, due to the end losses. The measured temperature is between 20 and 150 eV, for a plasma density of $10^{18} cm^{-3}$.

1 R.S. Massey, Z.A. Pietrzyk, D.W. Scudder, Physics of Fluids, March 1978.

* Work supported by US D.O.E., Contract AT45-1225 TA28, and NSF, Contract GK-41491.

Proposed Method of Measuring Directed Electron Velocities Using the Incoherent Regions of Laser Scattering. *B. A. Jacoby and T. M. York, The Pennsylvania State University.--With the presumption that a shifted Maxwellian velocity distribution adequately describes the electrons in a flowing plasma, the details of a method to measure their directed velocity is described. The system consists of a ruby laser source and two detectors set 180° from each other and both set at 90° with respect to the incident laser beam. The lowest velocity that can be determined by this method depends, of course, on the electron thermal velocity. One application of this diagnostic is the measurement of flow velocities in θ-pinch devices. Taking 5m linear Scyllas as an example where T_e=610ev, ne= $2x10^{16}cm^{-3}$, and T_i=3kev, the endloss velocity of roughly $\sqrt{T_i/m_i}$=$3.79x10^7$cm/sec can be detected with a signal-to-noise ratio of about 4.4.

*Work performed under the auspices of the U.S. Energy Research and Development Administration.

Direct-Readout Microwave Interferometer. J. FUJITA and K. MATSUURA, Inst. Plasma Phys., Nagoya U.--A new microwave interferometer has be developed and applied to the electron density measurement on JIPP T-II , a hybrid device of tokamak and stellarator at IPP, Nagoya. The interferometer generates an output voltage proportional to the number of fringe shifts and also output pulses which indicate the change of electron density for the convenience of data processing. The resolution is a quarter of fringe shift. The principle is based on the digitization of fringe shifts utilizing the phase detection of microwave signals with two-level modulation of source frequency. Careful adjustments of the circuits based on the detailed analysis of the operation were performed to keep the exact phase relations of the detected signals. With this system and 70 GHz microwave source, a fast change of electron density as high as 10^4 fringes per second has been measured at the tokamak operation of JIPP T-II. The second system has been just completed to improve the first version; achievement of better time response and installation of an interface to the CAMAC system.

<u>Computer Analysis of 2-D Holographic Interferograms</u>.* R. CONRAD and K. B. FREESE, <u>Los Alamos Scientific Laboratory</u>--End-on holographic interferometry has been used for many years for measuring electron line density profiles in a linear theta pinch. Recently a new program has been developed to analyze these data on a PDP-10 computer. The interferogram fringe patterns are digitized using a Summagraphics digitizer and results are displayed on a Tektronix 4014 graphics terminal. A special projection system has been built which makes digitizing polaroid pictures easier and improves resolution. Electron density is computed on a 2-D matrix and displayed as a 3-D plot. Total particle inventory, line density, and radius are also calculated. The data are saved on disk for future reference. Advantages of this method are its increased accuracy, its ability to analyze non-symmetric interferograms, and the establishment of a computer data base from which analysis can be expanded.

*Work performed under the auspices of the U. S. Department of Energy.

<u>A Fluctuation-Induced Transport Diagnostic Based Upon FFT Spectral Analysis</u>* E.J. POWERS, J.Y. HONG, Y.C. KIM, <u>Univ. Texas at Austin</u>; and J.R. ROTH and W.M. KRAWCZONEK, <u>NASA Lewis Res. Center</u>--FFT techniques are used to provide experimental insight into the relationship between fluctuation-induced transport and the experimentally observable spectral characteristics of the fluctuations.[1] Density $\tilde{n}$ and potential fluctuations $\tilde{\varphi}$ are digitized, their Fourier transforms computed, and a variety of spectra are generated. The most important is the transport spectrum which indicates how much transport (particles/area·time·Hz) is associated with the various spectral bands. The other spectra indicate the frequency dependence of (1) the rms amplitudes of $\tilde{n}$ and $\tilde{\varphi}$, (2) the phase angle between $\tilde{n}$ and $\tilde{\varphi}$, and (3) the degree of mutual coherence between $\tilde{n}$ and $\tilde{\varphi}$. This diagnostic has been used to study fluctuation-induced transport on the NASA Lewis Bumpy Torus, and several examples of the transport and related spectra will be given.

*Supported by NASA Grant 3089

[1]E.J. Powers, Nuclear Fusion 14, 749 (1974).

*Testing Transient Recorder Linearity.** K. A. KLARE, *Los Alamos Scientific Laboratory*--To provide permanent computer-accessible recording of waveforms, triggerable digital-to-analogue converters are connected to memories. After initial DC checking, a ramp or sine wave of known amplitude is connected to adjust or confirm the gain. Using the ramp and recording with a computer the frequency of occurance of each amplitude value (a histogram) one can measure the differential and integeral linearity of the device. Such dynamic measurements on six- and eight-bit recorders having 256 to 2048 time steps have shown design problems and the need for fine adjustment where amplitude measuring is critical.

*Work performed under the auspices of the U. S. Department of Energy.

Diagnostic Signal Transmission and Control using Fibre Optic Links

K Fullard, Culham Laboratory, Abingdon, Oxon, England.

A method of bi-directional transmission of data along low-cost 50metre fibre-optic links is described. The data is in digital form and is transmitted at 100kbaud. The infra-red (900nm) transmitting diode is used also as a receiver, thus avoiding complicated optical beam-splitting. Data can be read from the diagnostic, and control signals sent to it. The latter may cause, for example, readings to be taken by an ADC, a multiplexer to change channels, a counter to be reset or may be used by a DAC to generate analogue signals for probe bias. A multiplexer has been developed to allow signals to and from several devices to be combined. A microprocessor-based driver is under development to issue control commands and to record diagnostic data. The system incorporates several self-checking features and may be battery powered.

Diagnostic Techniques with Stand-Alone Capability

A H Read, Culham Laboratory, Abingdon, Oxon, England.

The Integrated Data Acquisition System (IDA) collects data from the principal experimental facilities at present in operation at Culham. IDA requires a large minicomputer at each experiment to control the local data capture equipment. Unprocessed data may be displayed locally or sent over a link to the central computer for processing. Computed results are returned to the local machine for display. This system, although effective when operating correctly is troublesome to the experimenters who await the return of results before the next shot. Future experiments plan to use small systems, dedicated to particular diagnostic techniques, employing the low cost minis now available. Such systems take advantage of operating systems developed for larger machines and may be programmed in FORTRAN for local processing and archiving purposes. However, when the central machine is unavailable the small systems take advantage of their 'stand-alone' features to ensure that experimental work continues.

Optical Standards for Plasma Diagnostics

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The accuracy available in EUV and x-ray radiometry is steadily improving. In general these improvements have come about both because of increased activity at NBS on these problems, and because of heightened interest in radiometric measurements in the various national laboratories leading to more intercomparisons and greater collaborative activity. The EUV standards available--synchrotron radiation, arcs, discharge lamps, absolute and calibrated detectors--now have good accuracy and availability covering the spectral region from the visible down to below 100 Angstroms. In the x-ray region, calculable detectors and well characterized line and continuum sources have been developed which serve as adequate standards from 1 keV to higher energies. The difficult region for radiometry, now subject to considerable effort, is the spectral decade 10-100 Å. A diode calibration facility has now been established at the NBS Synchrotron Ultraviolet Radiation Facility (SURF) which will allow the development and calibration of transfer standard diodes down to 50 Å. Also at NBS a well-characterized x-ray source is being developed for the region 8.0 keV to below 1 keV, and calibrated ionization chambers may soon become available to close the gap 10-50 Å. In another development at NBS, crystals are being highly characterized and their performance modeled with high accuracy. Thus the possibility exists for the development of x-ray radiometers over the spectral region 0.2 to 20 Angstroms. Synchrotron radiation, of course, can span the whole region of interest with calculable intensity. SURF presently has a beam line available for the calibration of spectrometer systems which has been successfully utilized for the calibration of plasma diagnostic instruments. A new facility for the exhaustive characterization of such spectrometers is under construction at NBS. We are designing a portable grazing-incidence monochromator, to be calibrated in this facility, which can be circulated to the diagnostics laboratories as a transfer calibration mechanism. Extension of such calibration services to wavelengths below 50 Å should be possible when the Brookhaven synchrotron radiation sources become available.

X-Ray Detectors for High Temperature Plasma Diagnostics.

R. D. BLEACH, Naval Research Laboratory, Washington, D.C. (30 min.)

X-ray emission from plasmas encountered in fusion and other high temperature research is indicative of energetic processes that involve electrons, atoms, and ions. The study of x-ray radiation in the energy range 0.1-100 keV provides information on parameters such as emissivity, temperature, density, size and composition of the source. These parameters are used, for example, to determine the energy in the plasma and how this energy can be channeled into fusion reactions. The large energy range of emitted x-rays can be accompanied by a large range of intensities which are observed in time intervals of 10^{-10} to 10^{-2} seconds. Different classes of x-ray detectors and their responses to pulsed x-ray emission will be reviewed. Specific devices such as solid state arrays and pyroelectric detectors which are just beginning to be exploited will be discussed. The talk will concentrate on the detectors themselves rather than entire systems which incorporate imaging or dispersive elements.

<u>A High Time-Resolving TV Camera System</u>. N. NODA and J. FUJITA, <u>Inst. Plasma Phys., Nagoya U.</u> -- A TV camera system is designed to investigate gross behavior of a plasma from the spatial distribution of its light emission. Silicon vidicon is used because of its high sensitivity, especially in IR range, and enduring characteristics for the excessive incidence of plasma light. Video signals are recorded with a video tape recorder, which starts and stops recording in normal speed with external triggering signals automatically synchronized with repetitive discharges. If necessary, the pictures are played back one field by one or in slow-motion mode. The system has also a function of taking pictures in "slit-scanning" mode, with which one can make an observation with faster vertical scanning rate than normal one. The maximum rate is one framing per 2.4 ms, which is seven times higher than in normal mode. The video signal of specified scanning line can be observed with an oscilloscope. The system has been applied to JIPP T-II , a hybrid device of tokamak and stellarator at IPP, Nagoya, for the purpose of investigating tangential view of the plasma. The system is found to be useful to monitor the plasma behavior and the interaction of the plasma column with the limiter.

<u>Plasma Photography in Doublet III</u>.* J. F. BAUR, D. R. BAKER, and E. S. ENSBERG, <u>General Atomic Co</u>.--
A unique optical/photographic/electronic system provides a detailed view of the noncircular cross section of the plasma in Doublet III. Interchangeable wide angle optical systems in specially designed ports permit tangential observation of the plasma chamber, including the inner and outer walls and the limiter, on both the midplane and the upper elliptic axis. Two 16-mm fast framing cameras are normally used at 1000 (capable to 10,000) frames per second. Three television cameras have been modified to provide a selectable, increased field rate of up to 420 fields per second. TV signals are recorded on videotape for archival purposes and on a magnetic disc for replay in slow motion (stop frame available) between shots for operator use. Plasma shape, position, and motion and (with filters) impurity dynamics are studied as a function of plasma control parameters.

*Work supported by the Department of Energy, Contract No. EY-76-C-03-0167, Project Agreement No. 38.

Diagnostics of Impurities on Tokamak Surface by Laser Induced Desorption* F. SCHWIRZKE, Naval Postgraduate School, and L. OREN, S. TALMADGE, R. TAYLOR, UCLA.-- Laser induced desorption and spectroscopic measurements of the coincident intensity changes of the impurity radiation have been used to diagnose surface impurity concentrations during tokamak discharges. A surface spot of about 10 cm^2 is flash-heated by an unfocused ruby laser pulse of 2J, 25 ns FWHM. This leads to instantaneous thermal desorption of loosely bound species (O, C, H). The locally increased atomic radiation is easily detectable. The first laser shot onto a new surface spot produces a large desorption even of metals (Cr, Fe). Consecutive laser shots produce much smaller signals. The experimental results show that loosely bound chromium and iron exist on the stainless-steel surfaces of the Macrotor tokamak. The presence of loosely bound metals may explain the observed large level of high-Z impurities in tokamaks.

*Research supported by DOE Contract No. EY-76-C-03-0010

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<u>Autoionizing States as an Insight into Dielectronic Recombination</u>.* W. E. Cooke and T. F. Gallagher, <u>SRI International</u>--We describe a simple experimental method for the laser excitation of arbitrary $n\ell$ states of alkaline earth atoms which allows the study of states optically inaccessible from the ground state. The method should be useful in acquiring basic atomic data to check theoretical calculations of dielectronic recombination rates. In recent experiments the autoionization rates have been measured as a function of both n and ℓ for Sr $5pn\ell$ states for $n \sim 15$. The autoionization rates are found to decrease as n^{-3} and very quickly with ℓ. Straightforward extensions of the method to study other relevant processes such as electric field effects will be discussed.

*Supported by AFOSR under Contract F44620-74-C-0059.

Detection of Low Density Atoms By Intracavity Dye Laser Absorption and Enhancement*. G. O. BRINK and H. S. LAKKARAJU, SUNY at Buffalo.--The mechanism of interaction of an atomic absorber placed inside the cavity of a cw tunable dye laser with the laser radiation is being studied as a detector of low density atomic or molecular species such as might be present as impurities in a plasma discharge. The experimental system consists of an ion laser pumped dye laser which contains an atomic beam of sodium inside the cavity to provide an absorber of narrow spectral width. As of the date of this abstract, about 10^6 atoms of sodium have been detected in absorption and less than 10^3 have been observed in enhancement. In this technique, the laser radiation is observed directly so that there is no problem of signal intensity compared with background radiation. Although there are several instances of enhancement being observed by other workers, their explanations do not seem to apply to the present results which extend to much lower atomic densities than have been previously reported. While the line shape observed in enhancement seems to be simple, that observed in absorption is complex, and there seems to be no satisfactory explanation of this at the moment.

* Partially supported by the United States Department of Energy under Grant No. EG77S024448.

Rapid Scanning of Spatial Distribution of Spectral Line Intensities in PLT Tokamak.* S. SUCKEWER, E. HINNOV and J. SCHIVELL, Princeton Univ.-- A rotating mirror system has been constructed to allow repeated scanning during the discharge, in either poloidal (vertical) or toroidal (horizontal) direction, of selected spectrum lines in PLT discharges. The maximum repetition rate for a poloidal scan is about 2 msec. The wavelength range, 2000-7000 Å, is presently being increased to include the Schumann region, 1200-2000 Å. Observations of radial profiles in the lines of HI, HeI, HeII, CIII, CV, OII and OV have revealed a number of curious asymmetries, which often change in time during the discharge, as well as with change of plasma conditions, e.g., a change of aperture limiters from tungsten to carbon. The asymmetries tend to be more pronounced for the lower states of ionization, i.e., closer to the plasma periphery, and they are particularly strong near the times of disruptions caused by plasma instabilities.

*Supported by U.S.D.O.E. Contract EY-76-C-02-3073.

Topics in XUV Spectroscopy of High Temperature Plasmas. N. J. PEACOCK, C. C. SMITH*, H. P. SUMMERS**, Culham Laboratory, Abingdon, Oxon, OX14 3DB, UK, (Euratom/UKAEA Fusion Association).--Electron densities, $n_e > 10^{21}$ cm^{-3}, have been derived with an uncertainty of ±20% from the line shapes of ionised emitters in solid target laser irradiation experiments. The method, which employs a modified Holtsmark distribution field[1] to describe the far wings of hydrogenic lines, can be extended to much higher densities with suitable choice of emitter charge and quantum states. In low energy-density plasmas such as Tokamaks, the XUV emission uniquely allows a derivation of the ion parameters such as impurity concentration profiles, the effective charge states and the ion diffusion velocities. Examples of these are shown. A new method of measuring diffusion rates of impurity ions which makes use of the radial profile of the relative intensities of intercombination and allowed lines of He-like ions is discussed.

*Imperial College, London. **University of Cambridge, UK
Submitted by R. S. Pease.
[1]C. F. Hooper Jr., Phys. Rev. Letts. 165, 1, 165 (1968).

EUV Spectroscopic Instrumentation for Plasma Diagnostics,* H. W. MOOS, W. G. FASTIE and R. K. RICHARDS. The Johns Hopkins Univ.--In conjunction with diagnostic studies, this laboratory is designing and constructing instruments specifically for magnetically confined high temperature plasmas. The design goals include stable and accurate wavelength and photometric calculation, very high mechanical and electronic reliability, and high vacuum quality compatible with both high purity plasmas and synchrotron radiation calibration sources. Additional goals are ability to be used in any orientation, small size and weight, and portability. Instruments in use and being developed include a 125 mm Ebert system, a 400 mm normal concave grating spectrometer, a one meter grazing incidence spectrometer, a two meter grazing incidence double monochromator and a dual-parabola plane grating grazing incidence monochromator. The accuracy of spectrophotometric calibrations and the stability during use on plasma machines will be discussed.

*Supported by US DOE.

A Spatial Imaging Detector for an EUV Monochromator,* R. K. RICHARDS and H. W. MOOS. The Johns Hopkins Univ.--An EUV detector system designed to simultaneously observe 22 spatial elements is under construction. Spatial images can be formed at any selected wavelength with 62.5 μs time resolution. One application is the determination of impurity fluxes and concentrations in tokamaks and other pulsed devices where limited data and shot to shot variation are a severe restriction; this detector gathers sufficient data for an Abel inversion from a single shot. The system components include a high strip current microchannel plate detector, sensitive pulse counting electronics, digital storage, and display. Details of the system and initial test results will be presented.

*Supported by US DOE.

Interpretation of ORMAK Impurity Radiation Data Using Simulation Models. E. C. CRUME, R. C. ISLER, and T. AMANO,* ORNL†--As reported earlier,[1] hydrogen gas puffing used to increase particle concentrations during neutral beam injection into ORMAK causes marked changes in the intensities of prominent oxygen impurity lines. To aid interpretation of these results we used a simple simulation code which solves coupled rate-diffusion equations for the ions assuming reasonable ad hoc values for diffusion and recycling neutral velocities. We improved this code, which uses only a few seconds of computer time on a PDP-10, and used it and a more complicated transport simulation code[2] in further analysis. Use of the transport simulation code, which requires a larger computer and more computer time, becomes feasible once the parameter ranges have been better defined using the simpler code.

*On leave from Osaka University, Japan.
†Operated by Union Carbide Corporation for DOE.
[1]R. C. Isler, E. C. Crume, and H. C. Howe, Bull. Am. Phys. Soc. 22, 1091 (1977).
[2]T. Amano and E. C. Crume, Bull. Am. Phys. Soc. 22, 1095 (1977).

Temperature Diagnostics Using Li-Like Satellites.#
R. U. DATLA*, L. A. JONES and D. B. THOMSON, Los Alamos Scientific Laboratory. A 60-kJ θ-pinch is operated at a filling pressure of 16 m Torr using a gas mixture of 2% neon and 98% helium. The He-like resonance line from Ne IX and its Li-like satellites as well as the L_α line from Ne X are observed with a Bragg crystal monochromator using a KAP Crystal and a pilot B scintillator and photomultiplier detector. Several photoelectric scans were made and the spectra were reproducible from shot to shot. The Li-like satellites produced by inner shell excitation had Ne VIII time history and are thus resolved from dielectronic satellites. The intensity ratios of dielectronic satellites to the He-resonance line are measured. The electron temperature of the plasma is deduced from those ratios using recent calculations of Bhalla et. al.[1] This temperature ranged from 200 - 350 ev during the time of occurrance of these satellites. A comparison between these measurements and measurements done by using 90° Thomson scattering will be made.

Work done under auspices of U. S. DOE.

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1 C. P. Bhalla, A. H. Gabriel and L.P. Presryakoce, Mon. Not. R. Astr. Doc. 172, 359 (1975).

The Ultra-Soft X-Ray Array on PLT. D. R. EAMES, S. VON GOELER, N. R. SAUTHOFF, and W. STODIEK, Princeton Univ.* -- The ultra-soft x-ray measuring system consists of an array of silicon surface-barrier detectors viewing a vertical crossection of PLT through a common, windowless slit. The detectors are sampled by transient recorders at various rates up to 1 MHz. An additional detector with moveable foils of 0.1, 0.4, 1.6, 6.4, and 12.7 μm Be differentiates between tungsten (∿250 eV), oxygen (570-670 eV), and iron radiation (730-1000 eV). The radiation from PLT will be interpreted in terms of the coronal equilibrium model.

*Work supported by U.S.D.O.E. Contract EY-76-C-02-3073.

<u>Analysis Techniques for X-ray Fluctuation Measurements on PLT</u>.* N. R. SAUTHOFF, S. VON GOELER, and W. STODIEK, Princeton University. -- The intensities of x-rays observed by the arrays of surface barrier detectors on PLT consist of integrals along lines of sight of the emission between roughly 1.5 kev and 15 kev. The inversion of these line integrals to yield local values of emission will be described for cases where the radiation consists of an equilibrium component $\varepsilon_0(r)$ and an oscillating spatially-varying part $\varepsilon_1(r) \cos(m\theta+n\phi-\omega t)$;[1] under these conditions, the local values can be determined by observing through a single window. In cases of mixtures of modes of different wave numbers (m,n) and non-rigid rotation, more views are required.

*Work supported by U.S.D.O.E. Contract EY-76-C-02-3073.

1. N. R. Sauthoff, S. Von Goeler, and W. Stodiek, PPPL-1379.

Determination of Spatial Distribution of Volume Soft X-Ray Emission from Plasmas. A. P. NAVARRO*, V. K. PARE, and J. L. DUNLAP, ORNL†.--The spatial distribution of the soft X-ray volume emission of plasma can be used to determine plasma shape. Theoretical expressions have been derived to relate local emissivity values to the chord measurements obtained by the detectors. This inversion procedure has been applied in a simulation process for the different plasma shapes expected in the ISX-B tokamak (circular, elliptical, D-shaped), looking for optimizations in the number of detector arrays and their positions, within the constraints of accessibility of the machine.

*On leave from J.E.N., Madrid (SPAIN).
†Operated by Union Carbide Corporation for the Department of Energy.

High Resolution X-Ray Spectrometer for Line Profile Analysis.* P. O. TAYLOR, and H. W. SCHNOPPER, Center for Astrophysics. -- We have studied a spectrometer concept whose initial application will be the measurement of ion temperature. At the heart of the instrument is a large, cylindrically bent crystal which subtends a range of Bragg angles at the entrance slit, located on the cylinder axis. The crystal focusses the reflected and dispersed rays back onto the cylinder axis where they are recorded by a linear, position-sensitive detector. Focusing properties of the cylindrical crystal, used in this way, allow acceptance of a large solid angle from a long narrow slit with minimal focusing abberations thus providing high throughput without loss of resolution. In addition, the crystal disperses a wide wavelength range onto the position sensitive detector allowing a significant range of spectrum to be recorded simultaneously. To record an adjacent region of the spectrum, the Bragg angle and the separation of the crystal from the telescope focus are both reset. Detector position and angle are also reset. Each crystal can operate through a Bragg angle range of 30° to $40^{\circ} < \theta_B < 70^{\circ}$ to 75°. *Research supported by DOE.

A High Resolution Crystal Spectrometer.*

M. BITTER, S. VON GOELER, M. GOLDMAN, K. HILL, R. W. HORTON, N. SAUTHOFF, W. STODIEK. Princeton University. -- A high resolution crystal spectrometer is being used to study the helium like iron lines emitted from PLT discharges at temperatures in excess of 700 eV. The spectrometer consists of a 6" x 1.5" x .030" quartz crystal (crystal cut parallel to the $22\bar{4}\bar{3}$ plane with a 2 d-spacing of 2.028 Å) bent to a radius of curvature of 333 cm in the Johann configuration and of a multiwire proportional counter. The energy resolution is 15000 which is mostly determined by geometric effects and the spatial resolution of the detector (.4 mm). Preliminary measurements on PLT have produced spectra similar to those of iron in solar flares.[1] These spectra show the main resonance line with sattellites on the low energy side, which have been ascribed to dielectronic recombination.[2] The interest in the high resolution spectrometer is, of course, the measurement of the ion temperature. The width of the resonance line is not inconsistent with Doppler broadening.

*Work supported by U.S.D.O.E. Contract EY-76-C-02-3073.

1. Grineva Yu. I. et al., Sol. Phys. 441, 29 (1973).
2. Gabriel A. H., Mon. Not. R. Astr. Soc. 99,160(1972).

Fe Charge-State Distributions in PLT from Bragg X-Ray Spectroscopy.* K. W. HILL†, S. VON GOELER, B. FRANKEL‡, R. HORTON, R. D. COWAN§, and J. HOVEY, Princeton Univ.--X rays from the 1s-2p transition in Fe^{17+}-Fe^{24+} ions in PLT plasmas were measured with a Johann curved-crystal spectrometer using a multiwire proportional counter. The resolution was 4 eV at 6400 eV. Line positions are in good agreement with those from solar flares[1] and calculations.[2] The charge state distributions in discharges having peak electron temperatures Te(0) from 700 to 1500 eV agree with coronal equilibrium calculations,[2] indicating an ion lifetime in the discharge center comparable to or longer than the equilibration time, based on L-shell ionization cross sections of Lotz[3] for Te(0)=800 eV and one-half the values of Lotz[4] for Te(0)=1500 eV.

*Work supported by USERDA Contract E(11-1)-3073.
†On leave from Oak Ridge National Laboratory.
‡The Hebrew University of Jerusalem, Israel.
§Los Alamos Scientific Laboratory, Los Alamos, NM 87544.

[1]Grineva, Yu I., et al., Solar Phys. 29, 441 (1973).
[2]Cowan, R. D., LASL Report LA-6220-MS (1976).
[3]Lotz, W., Z. Physik 206, 205 (1976); 216, 241 (1968).
[4]Datla, R. U., et al., Phys. Rev. 14A, 979 (1976).

<u>An Absolute Radiation Measurement and Comparison with Total Energy Loss</u>.* R. B. HOWELL, A. HABERSTICH, H. J. KARR, <u>Los Alamos Scientific Laboratory</u>.--The question often arises as to how much of the total energy loss is due to radiation. A photodiode was used to measure the radiated energy from the ZT-S toroidal RFP plasma. This photodiode was absolutely calibrated and had a wavelength converter between it and the incident radiation. The radiated power was integrated electronically to obtain radiated energy--normalized to the average photon energy and source-detector geometry. Using standard voltage and current diagnostics the input energy was also obtained by multiplying the analog voltage and current waveforms and integrating in time. The radiated energy signal and the input energy signal are then fed into digital sample and hold devices. Also digitally recorded are the toroidal and poloidal magnetic fields with five coils for each direction spaced along the minor radius. An on-line computer then takes the magnetic probe signals and with the assumption of pressure balance the plasma kinetic energy and magnetic field energy are obtained. The same on-line computer then allows an instant comparison of radiated energy loss to total energy loss.

*Work performed under the auspices of the U.S.D.o.E.

Detectors and Techniques for Energy Flux Measurements on ISX. C. E. BUSH, ORNL.*--Pyroelectric detectors, used very successfully on ORMAK , have also been used to make energy flux measurements on ISX-A. Time resolved measurements were made using single uncollimated detectors to monitor the total power loss to the walls and a 6-detector array of well-collimated detectors to determine the spatial distribution of the radiated power. The array will be described in detail and the resulting data and analysis discussed. Plans for a more extensive two dimensional (12 x 12, vertical-horizontal) array for ISX-B, where non-circular plasma cross-sections are expected, will also be presented. Unlike ORMAK, where the limiter was inaccessible and ISX-A, where the operational life time is short, a complete energy balance measurement is to be made on ISX-B, including monitoring of the energy flow to the limiters using an infrared camera.

*Operated by Union Carbide Corporation for the Department of Energy.

C. E. Bush and J. F. Lyon, ORNL/TM-6148 (1977).

MIRROR MACHINE DIAGNOSTICS*

Thomas C. Simonen
Lawrence Livermore Laboratory

A wide variety of diagnostics are employed by the 2XIIB group to measure plasma parameters. In this experiment, up to 7 MW (500 Amp. atom equivalent) of neutral beam power is injected to create plasmas of density $n_e \leq 1.5 \times 10^{14}$ cm^{-3}, mean ion energy $W_i \leq 13$ keV, and electron temperature $T_e \lesssim 140$ eV. These plasmas, of several liter volume, are confined in a 7 kG minimum-B magnetic field with a 2:1 vacuum mirror ratio. Neutral beam power is determined by a calorimeter positioned in the center of 2XIIB. Beam trapping efficiency is then determined with an array of detectors opposite the neutral beams. Plasma density is measured by microwave interferometry, neutral beam attenuation, Thomson scattering, and with a crossed neutral-beam and charge exchange technique. Ion energy is measured with a movable 15 channel magnetic and electrostatic charge exchange analyzer. Thomson scattering measures electron temperature. Residual ion cyclotron fluctuation spectral characteristics are measured with electrostatic probes and a 2 mm microwave beam. Ions escaping along magnetic field lines are detected with a gridded electrostatic analyzer. The tandem mirror experiment (TMX) and field reversal experiments in 2XIIB require additional diagnostics. The principle new parameter to be measured in TMX will be plasma potential using heavy ion beam probes. To measure magnetic field in 2XIIB, a Zeeman diagnostic is being developed. A recent development is the detection, with spatial resolution, of 3-MeV protons and 1-MeV tritons created by D-D reactions in 2XIIB.

*Work performed under the auspices of the U. S. Department of Energy under Contract No. W-7405-Eng-48.

Measurement of the Current Distribution in Tokamak Plasmas Using Neutral Lithium Beam Spectroscopy

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Max-Planck-Institut f. Plasmaphysik,Garching,EURATOM-Ass.,Germany

A detailed radial profile of the poloidal magnetic field has been measured for the first time on the Pulsator Tokamak using neutral lithium beam spectroscopy. In this method[1] the pitch angle θ of the magnetic field lines is locally determined by measuring the direction of polarization of the π component of the Zeeman-split, collisionally excited lithium resonance line at 6708 Å. The present measurement accuracy (limited largely by PM shot noise) of $\delta\theta \sim \pm 0.33°$ for integration times of the order of 10 - 20 ms is dictated by the relatively weak lithium neutral beam intensity of 5 - 10 $\mu A/cm^2$ (in the Pulsator torus) at a beam voltage of 6 kV. A new, more intense ion gun employing a directly heated ß-Eucryptite cathode is being built. Extraction of the lithium ions from the ß-Eucryptite and subsequent focusing and acceleration is accomplished by a modified Pierce-type anode-cathode configuration followed by an immersion lens. Plans are to eventually increase the beam voltage to 100 kV in order to facilitate penetration of the beam on large radius (ASDEX-size) Tokamaks. In the talk, the measurement method and ion source will be described and the latest Pulsator results presented. Applicability of the technique to present-day Tokamak plasmas will be discussed.

1) K.McCormick, M.Kick and J.Olivain; 8th Europ.Conf.on Controlled Fusion and Plasma Physics, Prague, 140 (1977)

Heavy Ion Beam Probing of Plasma Potential in Baseball Minimum-B Geometry.* G. THOKAR, J.T. WOO, W.C. JENNINGS, AND R.L. HICKOK, Rensselaer Polytechnic Institute.--The use of a heavy ion beam for plasma diagnostics in baseball type minimum-B geometry is being investigated for application to the end plugs of the Livermore Tandem Mirror Experiment (TMX). Of primary interest is the measurement of the space potential in the end plugs relative to the central section. Application to the baseball geometry is complicated by the convoluted coil configuration which interferes with beam trajectories and the strong field gradients which lead to defocusing of the finite width beam. Furthermore, in the TMX end plug, the plasma β is expected to exceed 50% and the space potential approaches the probing beam energy. These effects on the sensitivity and resolution of the system and the relative merits of probing mostly along the mirror axis and mostly transverse to it are being evaluated by detailed trajectory calculations. Results and estimates of beam probe and detection requirements, measurement capabilities and resolutions appropriate for TMX parameters will be presented.

*Work supported by DOE in part under direct contract and in part under subcontract from Lawrence Livermore Lab.

The EBT Heavy Ion Beam Probe.* K.A.CONNOR, S.P. KUO, F.M. BIENIOSEK, R.L. HICKOK, W.C. JENNINGS, P.L. COLESTOCK†, Rensselaer Polytechnic Institute.--A heavy ion beam probe is now in operation on the Elmo bumpy torus for the purpose of measuring the plasma space potential and possibly density and electron temperature. A 60 kilovolt accelerator is used to produce a beam of singly charged ions (usually rubidium) which can be steered into any part of the plasma midplane of a single EBT mirror section. A localized measurement of the space potential is obtained by energy analysis of the doubly charged ions that result from impact with plasma electrons in the same manner as previous beam probe systems. Provision has been made to permit energy analysis of the primary beam so that the normally relative potential measurement is made absolute. To increase sensitivity, the primary beam is chopped and synchronous detection is used. (EBT operates in a continuous mode.) Spatial resolution is approximately 1 cm^3 and the minimum potential change measureable is less than 5 volts. The details of the operation and construction of this system will be presented.

*Work supported by Union Carbide Contract SUB 7044.
†Present Address--Princeton University.

A Beam Probe System for the Central Region of TMX.* G. HALLOCK, K. SAADATMAND, W.C. JENNINGS, and R.L. HICKOK, Rensselaer Polytechnic Institute.--A heavy ion beam probe will be installed on the central region of TMX with the primary purpose of measuring the plasma space potential. The experiment presents several unique problems for beam probing due to the small vacuum magnetic field (500-2000 gauss), large size (coil radius = 90 cm), expected Beta ($\geq$ 0.5), and expected space potential ($\leq$ 1.5 kV). The small magnetic field dictates the use of a relatively low energy probing beam ($\leq$ 20 keV), which means the vacuum trajectories are distorted by both the finite β and large ϕ in the plasma. This results in an ambiguity in the spatial location of the space potential measurement, which can best be resolved by measurements on both primary and secondary ion beams. Computer simulations of the effects of both β and ϕ will be presented, along with the proposed experimental arrangement and the expected sensitivity of the measurements.

*Work supported by Lawrence Livermore Laboratories.

Heavy Ion Beam Probe Vector Potential Measurement.*
J.A. KOLAWOLE, T.R. PRICE, K.A. CONNOR, Rensselaer Polytechnic Institute--The heavy ion probe has been shown to be directly sensitive to the magnetic vector potential component in the direction of an ignorable coordinate;[1] thus, it could be used to measure the poloidal field of a tokamak. The hollow cathode arc facility used to develop the other measurement capabilities of the heavy ion probe has been modified to determine the feasibility of the practical implementation of this technique. Two axial conductors have been added to carry 1000 Amp current pulses which produce an axial vector potential component. The solenoid field is produced by discrete coils and thus suffers from the same lack of pure symmetry as does a tokamak; the field has a small periodic modulation. Numerical simulations indicate that the radial field contributions significantly alter the desired longitudinal invariance. However, it has been shown that for properly chosen injection conditions, the effect of the imperfect symmetry can be made arbitrarily small. Preliminary operation of this apparatus will be discussed.

*Work supported by DOE Contract EY-76-S-02-2229.A001.
[1]Tonetti, Connor, Bull. Am. Phys. Soc., 21, 1128 (1976).

<u>An Ion Beam Trajectory Code</u>.* TIMOTHY A. CUTLER and ROBERT S. HORNADY, <u>Lawrence Livermore Laboratory</u> - A magnetic field code (EFFI), an orbit code (ORBXYZ) and a graphics data display code (EUTERPE) have been linked together to form a particle trajectory analysis code of great capability. An array of beamlets representing a beam of finite cross section is projected through the fields. The fields which may be included are calculated values of the magnetic field from EFFI and analytic expressions modeling plasma diamagnetism and ambipolar potential. The calculated trajectories, the coils and vacuum tank may be viewed using cut planes and rotations with EUTERPE. By changing the charge the trajectory of "secondaries" may be followed. This code was assembled to evaluate data from the heavy ion beam probes planned for the TMX midplane and end plug.

*Work supported by US DOE Contract W-7405-Eng-48.

Plasma Diagnostics by Neutral Beam Probing. K. KADOTA, K. TSUCHIDA, Y. KAWASUMI and J. FUJITA, Inst. Plasma Phys., Nagoya U.--A new method using both techniques of a lithium neutral beam and spectroscopy has been developed to measure the spatial electron density profile of a plasma. This probing technique utilizes the photons emitted by impact excitation of the probing beam with plasma electrons. The photon flux is given by the product of the beam intensity, electron density and effective cross section for electron impact excitation. A lithium ion beam is formed from the thermionic ion emitter using β-eucryptite. The lithium neutral beam is produced by charge transfer with lithium vapor. The beam intensity is obtained from the measurement of the photon flux which is resulted from excitation of the lithium beam in collision with the working neutral gas. The cross section for this process is experimentally determined. The spatial electron density distribution of the ECR test plasma of T_e~10eV, n_e~$10^{11}cm^{-3}$ has been determined from the measurements of the local photon flux (6708 Å) emitted by two atomic processes above-mentioned. The comparison of the obtained results with those of a Langmuir probe and microwave interferometer proves this new method is of practical use in the space-resolved measurements of plasma parameters.

A Technique for Measuring Poloidal Field Via a Perpendicular Neutral Beam of H_2^0.* F. C. JOBES. Princeton University. -- If an energetic beam of neutral H_2 molecules is injected perpendicular to the toroidal magnetic field of a tokamak, then H_2^+ ions captured from this beam orbit in circles aligned with the pitch of the field. In the dissociation of some of these ions, an energetic neutral is flung off which is in the plane of the circle. A measurement of these neutrals can provide information on the pitch of the field and hence on the poloidial field. (Idea originally by W. Stodiek and S. Von Goeler.) The diagnostic (charge exchange) neutral beam on PLT is a good source of energetic neutral H_2 molecules. A camera has been devised that can detect neutrals which originate from along ∿2/3 of this beam path. This camera has a comb-like mask at its aperture. The position at the detector surface of the shadow of this mask (in the flux of neutral particles) determines the angle of the particles, and hence the pitch-angle of the field. Sufficient information is available in the detailed shape of the shadow to provide a correction for the spread in angle caused by the acceleration of the particles along the field line over some finite lifetime.

*Work supported by U.S.D.O.E. Contract EY-76-C-02-3073.

PLT Neutron Measurements.* J. D. STRACHAN, A. BHATTACHARJEE, P. COLESTOCK, W. STODIEK, & R. W. STOOKSBERRY.+ Princeton University. --

PLT plasmas emit $\lesssim 5\times10^{10}$ n/s thermonuclear D(D,n) neutron fluxes indicating central ion temperatures $\lesssim 2$ keV in agreement with charge exchange measurements. During 40 kV, 1 MW deuterium neutral beam injection $\sim10^{13}$ n/s beam-induced D(D,n) neutron fluxes occur while $\sim10^{14}$ n/s W(γ,n) photo-neutron fluxes occur during runaway electron dominated discharges. The flux is measured in the range $10^{7}\rightarrow10^{16}$ n/s with $\sim$10ms time resolution using an U^{238} fission detector and an array of 9 moderated BF_3 proportional counters. Calibration was achieved by collimating a BF_3 detector to observe a well-defined plasma volume. Discrimination between fusion and photo-neutrons is obtained by observing both the toroidal symmetry of the neutron emission and the neutron spectrum. The neutron spectrum is measured using NE213 liquid scintillators with pulse shape discimination and collimated He^3 ionization chamber. The radial emission profile was determined by observing the direction of recoil protons in emulsions.

+On loan from Westinghouse Electric Corp.

*Work supported by U.S.D.O.E. Contract EY-76-C-02-3073.

TFTR Neutron Diagnostics.* H. W. Hendel and S. W. Seiler, Princeton U.--The primary goal of the TFTR neutron measurements is the determination of the power multiplication factor (Q); however, information on the beam-ion energy distribution, beam-ion loss rates, ion temperature, tritium confinement and their radial and temporal dependences will also be obtained. The instrumentation includes a high-energy-resolution (up to 2%) spectrometer, a multichannel spectrometer, an activation system and detectors for the scattered neutrons. To cover a broad range of neutron fluxes and energies, the high-resolution spectrometer includes proton-recoil telescopes, ^{3}He detectors and scintillation counters inside an iron-plastic collimator with a 1-4 cm diam. 1.2 m long channel, and at least 1 m of shielding. Both tangential and perpendicular viewing relative to the plasma torus is planned, in the horizontal plane. The low-energy-resolution, vertically viewing multi-channel (10-12) collimator contains fission and scintillation detectors and uses the test cell floor as the front part of the collimator shield. The pneumatic-rabbit activation system, with 8 irradiation stations located near the vacuum wall, monitors global neutron emission without time resolution, but with limited energy resolution.

*Work supported by U.S.D.O.E Contract EY-76-C-02-3073.

Alpha-Particle Diagnostics on TFTR.* S. W. Seiler and H. W. Hendel, Princeton U.--As the CTR goal of an ignited fusion reactor approaches, determination of the confinement times of charged fusion-reaction-products becomes important, since they provide the internal heat source necessary to sustain the burn. TFTR bridges the gap between future reactor-size machines with (predicted) good confinement and present small machines with poor confinement and low reaction rates. To measure the flux of alphas (from D-T, or tritons from D-D) reaching the TFTR vacuum-wall, shielded ZnS scintillators will be used. The shield design utilizes the helical alpha orbit to put a minimum of 2.5 cm of Pb (or W) into any viewing direction seen from the detector, thus reducing x-rays of less than 400 keV to a negligible level and attenuating more energetic ones. Selecting the thickness of the ZnS detector equal to the alpha range (15 microns) reduces the gamma and neutron sensitivities sufficiently to allow measurement of alpha loss fractions (alphas escaping on first neoclassical orbit/source strength) below 0.1%. A poloidal and toroidal array of energy resolving detectors determines the global loss fraction for comparison with neoclassical theory.

*Work supported by U.S.D.O.E. Contract EY-76-C-02-3073.

Perpendicular Charge Exchange Diagnostic for ISX-B. J. T. MIHALCZO, G. H. NEILSON, J. F. LYON, and R. E. WORSHAM, ORNL.*--A perpendicular charge-exchange analyzer diagnostic beam combination is under construction for spatially resolved ion temperature measurements on ISX-B with high power neutral beam injection. The system is capable of simultaneous ion temperature measurements at 9 points along the vertical path of a diagnostic beam injected from below. The beam can be translated horizontally so that two dimensional profiles of the ion temperature in elliptical or "D" shaped high β plasmas can be obtained. The system contains 9 two-channel analyzers capable of mass and energy resolution. Thus, the time evolution of nine spatially resolved energy spectra for two different mass species can be obtained simultaneously. The analyzers employ velocity filters in which the electric field is stepped synchronously with the field in parallel plate electrostatic energy analyzers and thus provide spectra from ISX-B in 10 msec. Calibration data for one of the analyzer modules for incident H^o and D^o up to 50 keV is presented.

*Operated by Union Carbide Corporation for the Department of Energy

Mass-Energy Neutral Analyzer for ISX. G. H. NEILSON, ORNL*.--The effectiveness of neutral particle diagnostics is enhanced by adding mass analysis to the usual energy analysis. This enables the differentiation of a class of plasma ions (introduced by, e.g., cold gas, pellet, or beam injection) from the background plasma by using different mass species, H and D, to identify them. Such an analyzer, employing a seven-channel, 180° magnetic momentum analyzer followed in each channel by a coarse-resolution electrostatic energy filter, is used on ISX-A. Its spectral coverage $E_{max}:E_{min}$ is 10.6:1, the resolution $\delta E/E$ is 0.05 FWHM, and the mass rejection ratio is >100. Each channel may be set independently to detect either H^0 or D^0. The analyzer calibration in the range 0.5-10.0 keV, using H_2 and D_2 in the stripping cell, as well as neutral data obtained on ISX-A, will be presented. Plans for using this device as a tangential analyzer in conjunction with neutral beam heating and a diagnostic beam on ISX-B will also be discussed.

*Operated by Union Carbide Corporation for the Department of Energy.
[1]J. T. Mihalczo et al., this meeting.

<u>End Loss Analyzers on 2XIIB*</u>

A. W. MOLVIK, <u>Lawrence Livermore Laboratory</u>--The stability of magnetic mirror confined plasmas to the drift cyclotron loss cone mode is provided by unconfined warm ions.[1] These ions are lost along field lines to the end walls where their current and parallel energy distribution are measured by retarding potential gridded analyzers. Two analyzers have been used. One has 22 cm diameter grids that can analyze ions up to 3 keV, and a 1 x 5 cm entrance aperture that scans the plasma flux tube. The smaller second analyzer is used primarily for current measurements. These analyzers have the following features: 1) the angular acceptance is greater than 22° to accept all ions in the loss cone; 2) the perpendicular ion energy is contained by one gyrodiameter of axial magnetic flux between the entrance aperture and the grid supports; 3) low transmission entrance grids are used to attenuate the ion power, current, and density; 4) the collector can be biased to -1 KV to increase the space charge limited current.

*Work performed under the auspices of the U.S. Dept. of Energy under Contract No. W-7405-Eng-48.

[1]F. H. Coensgen, et al, Phys. Rev. Ltrs. <u>35</u> (1975).

Detection of MeV Ions from D-D Reactions in 2XIIB.* JAMES H. FOOTE, Lawrence Livermore Laboratory - A silicon surface-barrier detector located outside the mirror region has been used to observe 3-MeV protons and 1-MeV tritons, products of D-D fusion reactions, in 2XIIB. The detector can be moved about inside a compartment that has a 0.25-cm-diam. hole facing the plasma. Thus the detector is shielded, the reaction ions entering the compartment are well collimated, and the detector can be positioned to intercept the particles. Up to 3-μm-thick Al and 1.2-μm Au foils have been placed just before the detector to attenuate unwanted radiations from the plasma. Possible plasma measurements with this reaction-ion diagnostic in magnetic-confinement experiments include: reaction rate with better spatial and energy resolution than when detecting neutrons, radial spatial resolution with the detector outside the mirror region, axial resolution with the detector displaced radially near the midplane, plasma-ion temperature (from the energy spread of the MeV ions), and conceivably the average magnetic field in the plasma region experienced by the MeV ions (from the possibility of defining the detailed particle trajectories).

*Work supported by US DOE Contract W-7405-Eng-48.

<u>A Multi-Channel Magnetic Analyzer for Pulsed Plasma Sources</u>.* JOHN E. OSHER, <u>Lawrence Livermore Laboratory</u> - The detailed analysis of a pulsed plasma source generally requires a measurement of the appropriate ion energy distribution functions. A magnetic analyzer for mv/q with time of flight resolution of v is a common solution to this problem. However, if the pulsed source is not highly reproducible or if the target material is a mixture yielding several possible ion species it is desirable to make the analyzer multi-channel to allow determination of several points on each ion species energy distribution function during a single shot. The construction and calibration of an 8-channel magnetic analyzer is described. As an application, typical data for the N^+ to N^{7+} and H^+ ion distribution functions are presented for the case of the plasma target production in Baseball II using a 50 nsec 300 J CO_2 laser pulse incident from two sides on a 150 μm diameter NH_3 pellet.

*Work supported by US DOE Contract W-7405-Eng-48.

Measurements of Gettering Efficiency for A Simulated Divertor Plasma Flux.* M. YAMADA and D. K. OWENS, Princeton U.,--In order to estimate or analyze the divertor performance for tokamaks, data for particle-gettering efficiency at the divertor chamber are vitally needed. The QED-1 device at PPL has provided data of gettering coefficients for simulated (hydrogen) divertor plasma on Titanium walls, which will be used in the PDX divertor chamber. The hollow-anode arc-jet device produces a plasma column of ~ 1 cm in diameter, $10^{12} \lesssim n_e < 5 \times 10^{14}\,cm^{-3}$ and $T_i \lesssim T_e = 3 \rightarrow 15$ eV, confined by an axial magnetic field of 1 - 6 kG. The measurements are based on monitoring neutral gas density with respect to time in the divertor chamber of QED-1, after the plasma pulse is injected. A preliminary data imply that the plasma particles lose most of their momentum and energy together with changes when they hit the neutralizer plate. The data are checked by analyzing the neutral flux in the chamber, using a mass spectrometer.

*Work supported by U.S.D.O.E., Contract EY-76-C-02-3073.

<u>Charged Fusion-Product Detection in a Tokamak.</u> L. M. HIVELY and G. H. MILEY, U. of Illinois--Detection of high-energy, charged fusion product (fp's) bombarding the first wall in PLT and TFTR has been proposed[1] as a critical experiment for future reactor development. We model two detectors at the top and outboard side of the torus, shielded and facing away from the plasma so fp's can enter along gyrohelices[2]. The analysis is based on our previous work[3], but is complicated by the necessity to evaluate two factors: (a) the fraction of fp's reaching the vicinity of the detector from each plasma volume interval; (b) the fraction of (a) gyro-orbiting past the radiation shield into the detector. Finally, the summation of these contributions over the total plasma volume involves a 4D numerical integral. For PLT, the detector response varies several orders of magnitude with allowed changes in I_{PL} and T_{io}, and is proportional to B_0. Diagnostic uses include verification of fp transport and time evolution of the fusion source rate.

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[1]L. M. Hively and G. H. Miley, U. of Ill. Rpt. # COO-2218-40. [2]H. Hendel, PPPL, private communication. [3]L. M. Hively and G. H. Miley, *Nuclear Fusion 17* (1977) 1031.

MEASUREMENT OF THE MOLECULAR CONTENT OF LOW ENERGY DEUTERON OR TRITON BEAMS, F.E. Cecil and K. Killian, Department of Physics, Colorado School of Mines. The molecular content of low energy deuteron or triton beams is determined by measuring the absolute thick target yield of fast neutrons at times short compared to the target saturation time. New techniques for the measurement of the absolute flux of fast neutrons will also be presented.

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